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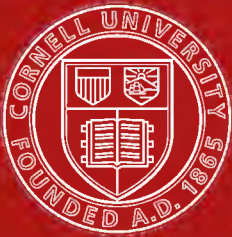
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MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

THE

GEOLOGY

OF THE COUNTRY BETWEEN

APPLEBY, ULLSWATER, AND HAWESWATER;

(EXPLANATION OF QUARTER-SHEET 102 S.W.,
NEW SERIES, SHEET 30.)

BY

J. R. DAKYNS, M.A., R. H. TIDDEMAN, M.A., F.G.S.,
AND J. G. GOODCHILD, F.G.S.

WITH PETROLOGICAL NOTES, BY THE LATE J. CLIFTON WARD, F.G.S.,
AND W. W. WATTS, M.A., F.G.S.

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P R E F A C E.

THE original geological survey of the area represented in the map (Sheet 102 S.W.), to which the present Memoir is an explanation, was completed as far back as the year 1876, and was the work of Messrs. W. T. Aveline, T. McK. Hughes, J. R. Dakyns, R. H. Tiddeman, J. Clifton Ward, R. Russell, W. H. Dalton, J. G. Goodchild, G. H. Lightfoot, and E. J. Hebert, the mapping being under Mr. Aveline's superintendence. The map as it now appears was issued in 1893.

Of the officers above named seven have retired from the service and one is dead. Some delay has consequently arisen in the preparation of a description of the map. The present Memoir has been arranged mainly by Mr. Dakyns and Mr. Goodchild; the contributions of the different surveyors being indicated by their appended initials.

The sheets of the county maps on the scale of six inches to a mile included in the present one-inch map are Cumberland 57, 58, 65, 66; and Westmorland 3, 4, 5, 7, 8, 9, 12, 13, 14, 15, 19, 20, 21, 22.

The area embraced by the map extends from near the head of Ullswater on the west to Dufton and Appleby on the east. As it thus embraces the north-eastern part of the Lake District, including Haweswater, Bleawater, and Brothers Water, it possesses much geological interest in its copious development of the Borrowdale Volcanic Series. It contains also the northern edge of the Shap granite boss, and in its north-eastern corner a portion of the remarkably interesting inlier of the Silurian Series at the base of Cross Fell.

Around the hills of Lower Silurian Rocks the Carboniferous system is well developed. Its red basement sandstones and conglomerates (Upper Old Red Sandstone) occupy a considerable area to the north of Ullswater, but southward they diminish to a thin series forming at the surface a narrow band which can be followed south-eastward lying unconformably on the older rocks

and passing conformably upwards into the base of the Carboniferous Limestone. The Limestone-series is fully developed. To the north of it lies a broad belt of the Penrith Sandstone followed by the Triassic formations of the Vale of Eden.

Some of the petrographical notes were left by the late Mr. Clifton Ward; the rest have been supplied by Mr. W. W. Watts.

ARCH. GEIKIE,

Geological Survey Office,

Director General.

28, Jermyn Street, London, S.W.,

21st December 1896.

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The work contributed by the several Officers of the Geological Survey is as follows :—

DAKYNs, J. R., 13-23, 68-69, 88-90, 102, 103.

DALTON, W. H., 45-52, 90-92.

GOODCHILD, J. G., 29-52, 72, 74-87.

HEBERT, E. J., 90.

RUSSELL, R., 5, 6, 61-68, 70, 71, 83, 84, 88, 90-92, 95-102.

TIDDEMAN, R. H., 52-59, 72-74, 92-95.

WARD, J. C., 5-12, 23-28, 59-61, 101.

WATTS, W. W., 6-12, 23-28, 44, 61.

THE GEOLOGY OF

THE COUNTRY BETWEEN

APPLEBY, ULLSWATER, AND HAWESWATER.

CHAPTER I.

INTRODUCTION.

Physical Features.

The country to be described in this memoir includes parts of Cumberland and Westmorland, and forms two distinct portions which correspond to differences of geological structure. The south-western portion consists of Lower Silurian rocks, mostly of volcanic origin, and is a mountainous district, which attains the extreme elevation of 2,663 feet above sea-level on High Street. This range is so called because it is traversed by a portion of the old Roman road from Ambleside to Carlisle. With the exception of a small triangular area in the extreme north-east, which is also somewhat mountainous, the remaining area, amounting to about two thirds of the whole, is occupied by beds of Carboniferous, Permian, and Triassic age, dipping gently to the north-east. This district, though it rises somewhat sharply, where it faces the Silurian mountains, to an extreme height of 1,315 feet in Crosby Ravensworth Fell on the west, is nowhere of a mountainous character; but consists rather of a series of elevated terraces, whose steep sides formed by the outcrop of harder beds face south-westward, and whose summits fall away gently with the dip towards the north-east.

The geological structure of the country is tolerably simple on the whole. The mountains are composed of volcanic rocks of the Borrowdale Series striking E.N.E., and consisting of alternations of ash and breccia with a few beds of contemporaneous trap or lava. The volcanic rocks are nearly everywhere faulted against older beds of clay-slate known as the Skiddaw Slates, which occupy most of the lower slopes between the rugged mountains and the Carboniferous escarpment. The clay-slates contain several beds of ash or ashy grit interstratified with them.

The Carboniferous rocks lie unconformably on the Silurian, with a general north-west strike. The basement-bed is a red conglomerate of varying thickness, formerly grouped with the Old Red Sandstone. It is succeeded upwards by red shale and sandstones and then limestones, which pass up gradually into the overlying Carboniferous strata. These consist of a great series of alternating beds of limestone, sandstone, and shale.

The Carboniferous rocks are themselves overlaid unconformably by a series of red sandstones and shales, the "Red Rocks" of the

Vale of Eden, which have been classed partly as Permian and partly as Trias for the reasons given in the sequel.

The Silurian rocks in the extreme north-eastern corner of the area are brought up by a fault, the most westerly of the three great Pennine Faults; and they form part of the narrow strip of these rocks which runs along the foot of the Carboniferous escarpment of the Cross Fell range, from Fell Dykes south-east of Hilton to a little north of Melmerby in Cumberland, a distance of about fifteen miles. This Silurian strip is rendered prominent even at a distance by the three steep conical hills known as Murton, Dufton, and Knock Pikes. Knock Pike, which is the only one that occurs in the area under description, reaches a height of 1,306 feet above sea-level.

The subdivisions of the Carboniferous rocks are given in the annexed Table of Strata. The red marl and red conglomerate at the base, correspond to the beds classed as Lower Limestone-shale and Basement Conglomerate in the Explanation of the adjoining area on the south.* The Shap Limestone (M) is the Ravenstonedale Limestone of that memoir, much attenuated in thickness. The sandstone, shale, and limestone, immediately above it are the Ash Fell Beds. The two limestones, L and K, together make up the thick limestone described as equivalent to the Melmerby Scar Limestone of the Pennine range. Thus the overlying limestone-shale series will correspond more or less with that generally known as the Yoredale Series; but any attempt to correlate individual beds with well-known members of that series must from lack of evidence be often very uncertain.

The rocks classed as Permian and Trias consist broadly of the following subdivisions: the lowest bed about Appleby is a breccia or conglomerate locally known as Brockram, succeeded upwards by other beds of sandstone and brockram: but in the north-western part of the Permian area, about Penrith, the lowest bed exposed is a thick mass of highly false-bedded sandstone, known as the Penrith Sandstone. These lower beds are succeeded by a set of clays and red marls containing gypsum and plant-remains. The marls become sandy towards the top, and pass up gradually into the highest bed, which is an evenly-bedded red sandstone known as the St. Bees Sandstone from the fact that St. Bees Head is formed by this rock. The beds immediately above the Penrith Sandstone contain magnesian limestone in some parts of the country, and are of Permian age. As however the Lower Lias occurs near Carlisle, and the St. Bees Sandstone is very like beds elsewhere classed as Trias, it has been decided to adopt Sedgwick's classification, as far as possible, and to take the Magnesian Limestone or, in default of it, the Plant Beds, as the top of the Permian; and, when both those obscure and insignificant beds fail us, to draw the line at the top of the Penrith Sandstone.

* *Geology of Kendal, &c.*, by W. T. Aveline and T. McK. Hughes. Ed. 2. Revised by A. Strahan. 1888.

Besides the above-mentioned rocks, there are also various intrusive masses, bosses and dykes, of igneous origin, seldom of any great extent, which will be described in their proper places. The chief of these igneous rocks is the Shap Granite, a small part of which occurs in this area.

With the exception of a small tract in the south, which drains into the Lune, and of another in the north, near Penruddock, which drains into the Petterill, the many streams flow, directly or indirectly, into the Eden.

The Silurian tract in the south-west forms part of the far-famed Lake Country. It includes the greater part of Ullswater, the wild and beautiful Hawes Water, and the mountain tarns known as Angle Tarn, Hayes Water, and Blea Water, the last being one of the finest tarns in the Lake Country.

Ullswater separates a small tract of Silurian rocks on the north from the main mass lying to the south of that lake. This again is clearly divided into an east and west portion by the range of High Street, which maintains a height of over 2,000 feet for nearly six miles in this area. East of this range, the Silurian country drains into the River Lowther, which rises in Wet Sleddale just west of the Shap Granite. West of High Street the drainage is into Ullswater and the River Eamont which flows out of it. The rivers Lowther and Eamont unite at Brougham Castle, the Roman Brovacum, near Penrith, and together flow into the Eden four and a half miles east of Penrith.

Table of Formations.

POST-GLACIAL. Peat, Alluvium, and River Gravels.

GLACIAL. Sand and Gravel, Morainic Detritus, and Boulder Clay or Till.

TRIAS { St. Bees Sandstone.
Red Marls with Gypsum.
Plant Beds with Gypsum and Dolomite.

PERMIAN { Penrith Sandstone = { Upper Sandstone
Upper Broekram
Middle Sandstone
Lower Broekram } of Appleby.

UPPER CARBONIFEROUS. Millstone Grit.

		Feet.
	Sandstone and shale.	
A.	Limestone of Bewley Castle.	
	Sandstone and shale.	
B.	Limestone of Kings Meaburn and Great Strickland	= { MAIN LIMESTONE } 120
	Sandstone and shale.	
C.	Limestone	= { FOUR-FATHOM LIMESTONE } 25
	Sandstone and shale.	
D.	Limestone of Grayber.	
	Sandstone and shale.	

		Feet.
CARBONIFEROUS LIMESTONE SERIES.	E. Limestone of Brackenslack. Sandstone and shale.	LOWTHER LIMESTONE } 30
	F. Limestone of Maulds Meaburn Edge Sandstone and shale.	
	G. Limestone of Johnny Hall's Trees.	REAGILL LIMESTONE } 55
	Sandstone and shale with coal.	
	H. Limestone of Little Strickland.	SIMONSTONE LIMESTONE } 35
	Sandstone and shale.	
	I. Limestone of Maulds Meaburn.	HARDRA SCAR LIMESTONE } 30
	Sandstone and shale.	
	J. Limestone - - - - -	180
	Sandstone and shale.	
	K. Limestone of Askam - - - - -	30
	Sandstone and shale with occasionally a thin limestone.	
	L. Limestone of Knipe Scar (fossils, chiefly brachiopods, abundant)	100
	Sandstone, shale, and lime- stone.	THE ASH FELL BEDS } 110
	M. Limestone of Shap, with sandy beds and quartz =	
	pebbles.	RAVENSTONE- DALE LIMESTONE } 120
	Red marl and shale.	
Basement Beds: Red conglomerate ("Upper Old Red Sandstone") - - - - -		50
UPPER SILURIAN {		Coniston Flags. Stockdale Shales or Pale Slates. Graptolitic Mudstones.
LOWER SILURIAN AND CAMBRIAN. {		Bala and Coniston Limestone Series. Borrowdale Volcanic Rocks and Milburn Group. Skiddaw Slates.
INTRUSIVE IGNEOUS ROCKS. {		Lamprophyres. Dolerite. Diorite. Felsite. Micro-granite. Granite.

NOTE.—The thicknesses given above were estimated by Mr. Russell from a horizontal section drawn in a north-east and south-west direction through the village of Newtown.

CHAPTER II

LOWER SILURIAN.

Area North of Ullswater.

The area north of Ullswater and the River Eamont is divided into three parts, geologically. A Lower Silurian tract in the south, an area of Basement Conglomerate next, and Carboniferous Limestone bordering the district on the north. The Lower Silurian is taken to include both Skiddaw Slates (which may in part be Cambrian) and the rocks of the Borrowdale Volcanic Series. In this chapter we describe the Lower Silurian rocks alone.

SKIDDAW SLATES.

The area over which the Skiddaw Slates occur north of Ullswater is but part of the like tract which extends upon the south and south-east side of the water. The ground seldom rises more than 400 feet above the lake, and in very few places as much. The slates, which are only exposed in the courses of some of the streams, are black and much cleaved. In Pencilmill Beck, Watermillock Common, the best section is seen; here the cleavage is often nearly vertical, and close cross-jointage gives rise, with the cleavage, to fracture in a pencil form, and a mill for the working of slate-pencils has been established, but is now in disuse. This Skiddaw Slate area is almost uniformly drift-covered, generally forming a striking contrast to the rougher, less cultivated, and somewhat craggy ground occupied by rocks of the Volcanic Series. Nothing can be said about the dip or strike of these black slates, and on all sides they appear to be faulted against the rocks of the Volcanic Series or the Conglomerate.

J. C. W.

The small district around Cocklakes Hill where Skiddaw Slate is shown on the map, does not admit of much description inasmuch as the limit of its extension eastwards is uncertain.

Immediately west of our present area, Skiddaw Slate exists in the cutting for the Cockermouth, Keswick, and Penrith Railway, on the north side of Tarn Moss and for some distance along the Penrith road. That this rock extends farther south has been proved by the bore-holes which were put down by the Moss Bay Iron and Steel Co., Lim., in the fields south of Troutbeck Station. Here Skiddaw Slate was found under the drift, at depths varying from 18 to 24 feet. Farther investigations by the same Company proved Skiddaw Slate under the Red Conglomerate in the field at the south end of the occupation road leading to Great Mell Fell and situated just under the Wood. Mainly in consequence of their known occurrence in such close proximity to this portion of country, but also on such general grounds as the thorough

examination of the surface-indications furnished, the Lower Silurian rocks have been extended eastwards in the manner indicated on the map. On the south and east the boundary between the Skiddaw Slate and Red Conglomerate could not be ascertained with accuracy, but on the north the line of the Springfield fault north of Swinescales Beck is more definite.

R. R.

BORROWDALE VOLCANIC SERIES.

The rocks of this series occur chiefly on, and both north and south of, Gowbarrow Fell (*see* Hor. Sect., sheet 118), but also occur in curiously-faulted rectangular areas among the Skiddaw Slates, at Hagg Wood, Birk Crag, and The Knott. These areas stand up as rather craggy heights above the surrounding and low ground of Skiddaw Slate, and beautiful views of the Lake are obtained from them, especially from Birk Crag, 1,045 feet in height.

Very few undoubted lava-beds can be detected, the best marked being a small outlier on Birk Crag, capped by breccia and cleaved ash (*see* Hor. Sect., sheet 119). Its character is that of a compact and blue crystalline rock.

[The specimen (E. 55)* from this locality is like the other hypersthene-augite-andesites (or -basalts) to be shortly described. In addition however to the larger porphyritic plagioclase feldspars which are aggregated into groups together with bastite pseudomorphs after hypersthene, there is a set of smaller feldspar prisms, embedded in a ground made up of feldspar microlites and grains with chlorite.—W. W. W.]

Upon the Knott there is, amongst the unmistakeable ash, some very trap-like rock, but this appears to be ash in a state of great alteration; at all events it is untraceable as a bed.

[A specimen (E. 179) from the Knott is an ash containing at least one marked andesite fragment, in which are sharp porphyritic plagioclase crystals like those which, slightly broken, are scattered through the bulk of the rock. There are also large pseudomorphs, probably after hypersthene, much shattered and injected with quartz mosaic, calcite, and chlorite. The matrix consists of minute feldspar microlites and grains, with iron-ore dust.—W. W. W.]

The general character of the ash over the whole area under discussion is that of a crumbling, feldspathic, oftentimes purplish, and roughly cleaved rock, showing extensive alteration in parts, but with the fragmentary character clearly seen in others. Occasionally the highly altered ash bears garnets, and is very compact, blue, and trap-like, as just above Woodhouse and about Priest's Crag.

[The rock of Priest's Crag (E. 168) is a hypersthene-augite-andesite. The porphyritic plagioclase feldspar is fresh and zoned,

* The reference-numbers are those attached to the rock-slides in the Petrographical Department of the Geological Survey Office, London.

the bands running parallel to the outlines of the crystals, which are therefore not clastic; no augite is left, but pseudomorphs of calcite probably represent it; there are also bastite replacements of hypersthene. These constituents, together with iron-ores, are embedded in a minute microlithic matrix consisting of striated feldspars set in much chlorite.—W. W. W.]

Those dips which are seen along the line of junction with the Skiddaw Slates clearly show the faulted character of the junction. The cleavage in the ash dips generally to the south-east at a high angle— 75° to 85° .

The ash forming the narrow band upon the north side of the long east-and-west fault is of a very crumbling and felspathic character, as is seen a little to the south-west of Bennethead. The extension of this band in an easterly direction is somewhat uncertain.

INTRUSIVE ROCKS.

Among the Lower Silurian rocks the only case of intrusion seems to be at Airy (Aira) Point, just where Airy Beck empties itself into Ullswater. Here a mass of diorite occurs in the midst of the Skiddaw Slate, and is sometimes used for road-metal.

[Judging by the other rocks intrusive into the Skiddaw Slate of the area, this rock is not unlikely to be a diabase, probably containing uranite; unfortunately no specimen has been preserved.—W. W. W.]

Area South of Ullswater and West of the High Street Range.

This area includes two tracts of Skiddaw Slate, bordering the lake, and a highly mountainous country made up of rocks of the Volcanic Series.

SKIDDAW SLATES.

This formation occurs over a triangular area three miles in length, upon the east side of Ullswater, from Howtown to Pooley Bridge; and over a small and somewhat rectangular area immediately south-west of Sandwick.

Area between Howtown and Pooley Bridge.—The character of the ground is undulating, but low. The slate is mostly hidden by a covering of Drift, but may be seen in some of the stream courses, its appearance being that of an ordinary clay-slate.

Sandwich Area.—The south-eastern boundary of this small tract is believed to be unfaulted, and is well marked by the coming on of marshy ground. The south-western boundary is clearly a fault, directly crossing the strike of the Volcanic rocks immediately to the west. The slate, though generally covered by Drift, is well seen in the small beck which joins Scalehow Beck, and beside a small

plantation, in the bed of the stream, there occurs a grey-blue, dark-spotted rock, weathering like greenstone, exposed for a few feet in the midst of the slate. A microscopic examination of this petrologically doubtful rock reveals the following structure. A great deal of diffused chloritic matter in a felsitic-looking base; quartz grains rather abundant; pyrites; vesicles filled with chlorite. This rock may be an unaltered volcanic bed mixed with sedimentary matter, or it may represent a small intrusion of diabase.

[E. 94. A dyke in the Skiddaw Slate S.E. of Scale How Wood (six-inch map, 12 N.E.) is a much decomposed diabase still showing traces of its large feldspars, while the augites and amygdaloids are now replaced by quartz, which is often idiomorphic, by calcite, and chlorite.—W. W. W.]

BORROWDALE VOLCANIC SERIES.

The rocks of this series occur under the following forms:—1. Contemporaneous Traps (Lavas). 2. Volcanic ashes and breccias. 3. Cleaved ashes and breccias. 4. Highly-metamorphosed Volcanic rocks. A conformable passage upwards from the Skiddaw Slate to the Volcanic Series may be seen in Swarth Beck, one mile N.E. of Howtown.

1. *Contemporaneous Traps (Lavas).*

In the tract north of Hayeswater Gill beds of lava are not very numerous. They may however be well studied on Hallin Fell, near Howtown; at various points on the Beda Fell ridge; and on Place and Birk Fells. Representative specimens taken from each of these localities may be thus described. *Lithologically*, they consist of a compact greenish-blue base, with somewhat of a conchoidal fracture and containing small porphyritically-embedded crystals. *Microscopically*, the base is crystalline, though much obscured by chloritic matter; it does not however display such a minutely feldspar-crystalline structure as is the case among many of the lavas of the district, for there are, besides the needles, many medium-sized feldspar crystals, and some large ones, for the most part certainly of plagioclase. No augite is found in an unaltered condition. Magnetite, and black patches which may be limonite, occur.

[Several specimens from these localities have been cut and they show that there is considerable variety in the lavas. Some are undoubted andesites, while others are too basic to be placed unreservedly in this division, and belong to the division called by Messrs. Harker and Marr* basalts without olivine, and by some other geologists, basic andesites. To the former class of augite-andesites belong the rocks of Hallin Fell (E. 11) and Round How, Place Fell (E. 54). These rocks have large porphyritic crystals of plagioclase generally too decomposed for precise

* Quart. Journ. Geol. Soc., vol. xlix. (1893) p. 359.

identification, and aggregated into groups (glomeroporphyritic structure), augite represented by chloritic pseudomorphs, and a second generation of lath-shaped plagioclase generally fresh and graduating down to the felspar microlites of the ground-mass. Hypersthene appears to be absent from this set, but the shape of the pseudomorphs does not allow a positive statement on this point, while prisms of apatite are fairly abundant. The other set, which must be called hypersthene-augite-andesites or -basalts, is represented by specimen E. 59 from Haig Crag, and E. 20 from Beda Fell. These show porphyritic aggregates consisting of much plagioclase felspar with pseudomorphs after hypersthene and, possibly, augite, embedded in a matrix, usually microlithic, but occasionally cryptocrystalline with few microlites, of the same character as that of the augite-andesites, but sometimes without any trace of the second generation of felspars mentioned above. Pyrites and ilmenite are present in these rocks.—W. W. W.]

These lavas are generally variable in thickness, sometimes rapidly dying away.

A fine series of lavas alternating with volcanic ash may be studied on either side of Threshthwaite Cove. The best course to take in studying these in the field is to ascend Hartsop Dod (to the east of Brothers Water), follow the horse-shoe-like ridge in a southerly direction as far as Threshthwaite Mouth, and then return northwards along Gray Crag, down to the village of Low Hartsop. In this way all the various beds will be crossed. As is so frequently the case, the individual lava-flows cannot be traced continuously for any long distance. Four samples of these lava-beds have been sliced and the following results obtained :—

Lava b. (E. 10). W. of Threshthwaite Cove.

Lithological.—Compact base with small reddish felspar crystals, and vesicles filled with calcite.

Microscopical.—The felspar-crystalline base much obscured by chloritic matter. Larger crystals of felspar a great deal altered. No unaltered augite. Magnetite. Vesicles filled with calcite.

Lava c. b. e. (E. 4 and 8). W. of Threshthwaite Cove.

Lithological.—Finely-granular base with small disseminated crystals, and vesicles.

Microscopical.—Base of minute felspar-needles with porphyritically-embedded crystals of orthoclase and plagioclase. A great deal of chlorite or viridite and no distinct or unaltered augite. Magnetite.

Lava f. (? E 1). W. of Threshthwaite Cove.

Lithological.—Somewhat compact base with disseminated pink felspar crystals, and iron-pyrites.

Microscopical.—Crystalline base made up of somewhat broader felspar-prisms than usual, some of which seem to be orthoclase.

The intermediate augite (or hornblende?) grains seem to have been converted largely into epidote (?). Magnetite rather scarce. Vesicles edged with quartz and filled with chlorite. In one part these vesicles are all crowded together and the intermediate matter has a minutely crystalline structure.

[Four lavas from N.E. of Threshthwaite Cove (E. 1, 4, 8, 10), present most of the characters already described in the augite-andesites. There are three generations of felspar present, the first mostly occurring in single individuals and but rarely aggregated into groups; there is little doubt but that augite was originally present and hypersthene absent; minute iron-ore dust, crystals of apatite, and a good deal of epidote are present in the specimens. The slide E. 1 apparently contains the edge of a diabase intrusion. E. 69 from east of Threshthwaite Cove has a finer base and its augite pseudomorphs are grouped with the porphyritic felspars. Apatites and large sphenes are present in this rock.—W. W. W.]

The rock forming the Pikes, near Angle Tarn, is a compact tabular lava, dipping at a very high angle.

2. *Volcanic Ashes and Breccias.*

North-east of Howtown a great thickness of breccia and coarse ash is exposed dipping north-eastwards at angles of from 30° to 40° . The thick breccias forming the upper part of Birk Fell are probably somewhat higher in the series.

Winter Crag, Beda Fell, is a good example of the way in which coarse ash and breccia more readily form rough crags than do the finer varieties of ash or even some of the traps.

A peculiar breccia occurs S.E. of Birk Fell Slack; the fragments are embedded in a pink felspathic paste weathering brown. The whole is suggestive of tuff or volcanic mud and breccia, since the paste has every appearance of having been soft at one time.

Upon the High Street range much of the felspathic ash is intensely decomposed, and hence gives rise to a crumbling grass-growing soil.

Over the greater part of the area north of Hayeswater Gill, the dip of the various ashy deposits is south-easterly, and on Birk Fell the amount averages 40° for a considerable distance.

Half-a-mile east of Pooley Bridge is How Hill, formed of volcanic rocks. It would seem, from the shape of the ground, to be a small outlier, upon Skiddaw Slate, and to be faulted on the east.

3. *Cleaved Ashes and Breccias.*

In many parts the ashes, and sometimes even the breccias, where not extensively metamorphosed, are highly cleaved and good workable slates occasionally occur, as in Caudale and upon Place Fell. The strike of the cleavage is very constant, and generally about north-east. Usually the cleavage-planes stand nearly vertical.

4. *Highly-Metamorphosed Volcanic Rocks.*

Besides that usual amount of metamorphism to which all the Volcanic rocks are subject, there frequently occur tracts over which metamorphic action has worked such a change as often to efface the original character of the rocks. Thus ashy beds become almost indistinguishable from those of lava or from trap of an intrusive nature. The district around Angle Tarn is an example, for here it is almost impossible to distinguish between ash and lava. At Rampsgill Head the rocks have quite a porphyritic appearance, and indeed it is very possible that here there may be some intrusions, yet a careful search will generally reveal traces of fragmentary structure upon weathered surfaces, even where the interior of the rock is most highly crystalline.

[Two rocks (E. 71 and 72) from Rampsgill Head and one (E. 60) from N. of Rampsgill Head belong to the same type as the Threshthwaite augite-andesites. There are usually aggregates of porphyritic plagioclase, no hypersthene, pseudomorphs of augite, not in great plenty, with iron-ore dust, and secondary calcite and epidote embedded in a matrix of fine felspar microlites. In E. 60 the felspars are clear and fresh-looking but contain much white mica.—W. W. W.]

Again, the cliff due north-east of Low Hartsop, is formed for the most part of breccia, but this breccia is so compact and trap-like that the fragments are likely to be at first overlooked.

INTRUSIVE ROCKS.

On Brock Crag, to the north of Hayeswater Gill, a curious patch of intrusive rock occurs, which on its northern side is likely to be mistaken for a contemporaneous bed, while its southern side clearly displays considerable change of level relatively to the general bedding around. Two specimens of this rock have been microscopically examined, with the following result:—

Lithological.—Compact blue base with small scattered crystals.

Microscopical.—Felspar-crystalline base but very chloritic. Embedded crystals of felspar, much altered; augite, and magnetite.

The rock in fact would seem to be an altered dolerite, or one nearly allied to that class, and may be conveniently termed a diabase.

[The specimen E. 82 from Brock Crag is a very characteristic hypersthene-augite-andesite or -basalt. The matrix consists of minute felspar microlites, often mere skeletons, embedded in a brownish glass, which is only very slightly altered and still isotropic. There are unmistakeable pseudomorphs of hypersthene, well-preserved crystals of plagioclase, occasionally aggregated, and also separate aggregates consisting solely of fresh augite, allotriomorphic internally but idiomorphic externally. Iron-ores and secondary quartz occur. E. 78, from the same locality, is probably the same rock very much altered.—W. W. W.]

Another case of a somewhat similar diabase occurs half-a-mile south of the summit of Hartsop Dod, and its affinity with the neighbouring lava-flows should be noted. Two specimens of this rock have also been sliced :—

Lithological.—Dark fine-grained matrix with augite crystals and vesicles.

Microscopical.—Crystalline base made up of small felspar needles, with mingled chloritic matter. Scattered augite crystals of some size. Magnetite and black bars (pyrites?). Vesicles filled with chlorite.

[Specimens E. 80 and E. 81 from Caudale Moor to which this description probably applies, are remarkable rocks. The aggregates of porphyritic augite are quite fresh; they are set in a ground consisting of short, stumpy, felspar prisms associated with minute granular augites. There are large pseudomorphs in chlorite, some of whose shapes are suggestive of olivine, while others are more like felspar or hypersthene. Probably they represent the latter, as there are a few granular aggregates which may have replaced felspar. But they are penetrated by an enormous number of needles of actinolite set in at least three directions, so that all those in one direction extinguish simultaneously. The ground-mass is obscure. The rock is likely to have been a hypersthene-basalt with little porphyritic felspar. In this place should be mentioned the rock E. 93 mapped as an intrusion on Swarth Beck (7 S.W.). It is an andesite, apparently without porphyritic augite, but containing three generations of felspar, the earliest being large and aggregated into groups of which the constituents are idiomorphic externally only, the second are lath-shaped, clear, and smaller, and the third, minute microlites associated with the epidote and calcite of the base. —W. W. W.]

FAULTS.

Some of the faults have been already incidentally mentioned. The smaller ones require no further explanation than the map itself offers.

The fault shown as bounding the large triangular Skiddaw Slate area on the south-east, is rendered necessary by the manner in which, north-eastwards from Swarth Beck the various beds of Volcanic Series strike full against the line of junction of the two formation. The straight Vale of Fuesdale is traversed by a north and south fault.

The fault ranging north-west from Beda Fell and just east of Long Crag throws down on the north-west, and as has been already noticed, brings at one part of its course the Skiddaw Slates against the Volcanic rocks.

J. C. W.

CHAPTER III.

LOWER SILURIAN.

Area between the Carboniferous Rocks and the High Street Range.

This district comprises the Silurian area east of the crest of the High Street range; and extends from the Carboniferous escarpment of Moor Divock in the north to the granite area of Wastdale Crag in the south. It includes an irregular tract of Skiddaw Slate on the south-west side of the River Lowther, a large tract of the Volcanic Series, and a small area of Shap Granite.

SKIDDAW SLATES.

The most northerly exposure of this formation is at Butterwick: the rock is seen in Gill Beck, between Gill Head and Butterwick, and at intervals on the hillside as far as Low Roughill (pronounced Ruffle) westward; and southward as far as Pow Beck: the dip is not seen, but the neighbouring volcanic rocks are striking against the Skiddaw Slates so that these last seem to occupy a triangular area between Butterwick, Roughill, and Bampton, bounded by two faults and the alluvium of the Lowther. The Skiddaw Slate is again seen immediately south of Bampton. Here for a short space there may be a base to the volcanic rocks: but near Hungerhill the latter are thrown down by a fault to Walmgatefoot, whence the base runs above Walmgate, where Skiddaw Slate is seen, and below the dwelling known as Eastward, up to the fault passing near Thornthwaite Hall. The Skiddaw Slate is seen along the hillside and in the banks of Hawes Water Beck, and appears to pass up gradually into the volcanic rocks, so that it is somewhat uncertain where the base of the latter should be drawn.

On the east side of Hawes Water Beck, the Skiddaw Slate is seen in several places on the hillside between that beck and Swindale, in which dale also it is found frequently exposed on both sides of the valley as well as in the beck nearly as far south as Swindale Foot.

In this area ambiguous beds of gritty ash or ashy grits are found interstratified with the ordinary shaly Skiddaw Slate. One of these beds forms a prominent ridge of rock between Toathmain and Rawhead, traversed by thin veins suggestive of copper: the dip could not be made out; but the ridge, which probably runs along the strike, trends nearly north and south to a part of the beck where interstratifications of calcareous and gritty ashes with Skiddaw Slate are well seen. Here however the beds have a different strike, varying from E.S.E. to S.S.E., and dipping at angles of from 55° S.W. to vertical or even inverted beds. The general strike of the beds at this point would carry them up to an exposure of similar gritty ash, containing fragments of

Skiddaw Slate, which is seen just within the inclosures near Rayside (pronounced Racet) Gill. Ashy beds are also seen in the Skiddaw Slate in this gill near the footpath from Rayside to Tailbert Head. Similar ash is seen with thin interbeds of slate dipping N. by W. at 65° at the bend of Swindale Beck below the old Slate Pencil Mill. The road up Swindale Beck passes close by this old mill: and in the adjoining quarry there is a very good section of ordinary Skiddaw Slate containing bands of nodules, by means of which the beds are found to be dipping at 35° to the S.E.: higher up however we have discordant dips, probably due to a prolongation of the Thornthwaite Hall fault.

The Skiddaw Slate of Swindale is certainly faulted against the volcanic rocks on the west; because the latter, which here consist of compact blue trap interstratified with beds of ash, strike directly against the Skiddaw Slate, and end abruptly in a steep craggy bank along the foot of which water breaks out at intervals for the distance of nearly a mile.

On the east side of the dale the faulted nature of the boundary is not so unmistakable; but the general straightness of the line and an apparent discrepancy in the strike of the two sets of rocks indicate here, too, a probably faulted junction. The volcanic rocks on this side are fine massive ash with some trap-like portions: they are dipping at angles of 28° to 45° towards E. and S.E.: and are apparently regularly overlaid by interstratifications of Skiddaw Slate and ash; but at Tailbert where these beds are seen there is much disturbance. From Tailbert downwards the whole length of Rayside Gill, as far as the Rayside and Tailbert footpath mentioned above, is occupied by ordinary Skiddaw Slate, dipping at high angles with a general N.N.E. strike, and without any mixture of volcanic material; for the bosses of igneous rock, which project through the slaty ground W. by N. of Tailbert are of a character generally indicative of intrusive rocks. Below the junction of Rayside Gill with Swindale Beck, the latter stream is occupied by Skiddaw Slate in beds, vertical, or highly inclined to the east or west as the case may be.

Between Goodcroft and Fairy Crag bridge a small mass of beautiful quartz-felsite interrupts the Skiddaw Slate for a space: on the east side of this intrusion the Skiddaw Slate is found occupying the rest of the beck with a steady strike and well-marked dips ranging from 45° to 75° W.S.W.

Along the course of the River Lowther, above its junction with Swindale Beck, we have an ascending series of beds, persistently striking W.S.W. on the whole, and consisting of Skiddaw Slate and gritty ash nearly up to Keld. This series we will now describe in order, going up stream. The lowest section is in Skiddaw Slate just below Rosgill Hall Wood. The beds in the stream are dipping at 35° to the S.E.; but at the edge of the wood they are contorted. The next set of beds seen are gritty and calcareous ash, in the wood, with thin seams of Skiddaw Slate, dipping at 25° to the S.E. by S. The upper part of these beds is well seen in a little cliff on the north side of the river,

where the rocks appear to dovetail with Skiddaw Slates; and beds of the latter, dipping at 15° to the S.E. by S., occupy the bed of the stream right up to the cliff: but from the smashed appearance of the ash beds and the presence of quartz veins, there is probably a fault running along the face of the cliff and parting the two sets of beds. The next section is below the Abbey Bridge, where we have Skiddaw Slate dipping at 35° to the S.S.W. with a thin band of interstratified ash near the top: these slates are succeeded by a bed of ash containing large concretions; and this by Skiddaw Slate at the ruins of the old bridge, but the dip is not clear here. There is possibly a strike-fault here, as the beds appear to be crushed, and the spot is on the line of a fault. The next section is in a bed of massive ash, of a reddish-green colour, forming a bank on the west side of the river immediately south of Shap Abbey: then at the bend of the river south of the abbey we have ash dipping at 60° under Skiddaw Slate: and the bed of the stream is occupied by both rocks curiously faulted against each other.

Above this point unfortunately the beds are quite hidden by Drift for some distance. The next section is near the confluence of Lanshaw Sike. Here we have contorted beds of Skiddaw Slate in the stream adjoining a crag of light blue sandy ash containing pebbles of slate. The relation of the two sets of rocks is not seen just here; but a few yards higher up the ash reaches half across the stream, with a dip eastward, and strikes against the Skiddaw Slate on the south: this last is seen a little further south to dip at 65° and 85° to the S.S.W. and thus to strike against a mass of grey ash weathering rusty, which forms a little crag on the west side of the river. The next bed going up stream is a compact blue calcareous ash with slate fragments, succeeded by a mass of cleaved rough ash in which there is a narrow band of Skiddaw Slate striking N.E. by N. This brings us to the foot of Keld Gill, which is occupied by massive grey ash with slate pebbles. Beyond this point the only Silurian rocks seen along the River Lowther belong to the volcanic series, but Keld Gill and Thornship Gill as well as Lanshaw Sike exhibit beds of Skiddaw Slate. The only section in Lanshaw Sike, besides that at the foot already mentioned, is quite at its head, where Skiddaw Slate is seen apparently dipping at 70° to the W.N.W. The part of Keld Gill immediately adjoining the exposure of ash at the foot is obscured by Drift, but at the first strong bend Skiddaw Slate is seen apparently dipping at 62° to the W.N.W. A little further on a boss of ash is seen close to the beck: this is certainly the same bed as that which forms White Crag, which is striking for it: a few yards to the east of White Crag, Skiddaw Slate is seen on the moor on the strike of the beds at the bend of Keld Gill. On the west of White Crag we have a small bank of well-bedded Skiddaw Slate dipping W.N.W. at from 45° to 55° ; and again to the west of this, more Skiddaw Slate occurs in Keld Gill, dipping at 35° in the same direction. Close by on the hillside above there are beds of trap and ash, which appear to be parted

from the slate by a fault as the beds strike towards each other. Another exposure of Skiddaw Slate occurs in Thornship Gill between Bleak Dod and the bield lower down the stream. There is a continuous section of slate for the distance of 16 or 17 chains: the beds have a general N. and S. strike along the stream north of the Dod, the dip being at angles of 30° to 60° to W. by N. and W. by S.: but beyond the bend the beds are dipping south, and south by west at 25° to 50° , and beyond the next bend we have beds of gritty ash with a thin seam of slate dipping at 50° E. by S. and thus striking at the Skiddaw Slate last seen. Hence there is probably an east to west fault between the two sets of rock; but the gritty character of the ash and the seam of interbedded slate point to these beds being near the limit of the volcanic area.

I have now described sufficiently all the more important exposures of Skiddaw Slate. In a country so covered with Drift it is impossible to be sure of the structure, and different observers will probably continue to take different views; but as the alternations of ash and slate seen in the Lowther are not to be traced westward, where instead thereof we have a mass of pure and simple Skiddaw Slate, there may be a fault between the two sets of beds, probably throwing up on the west. The discordant strike of the Skiddaw Slates and of the volcanic rocks, which form the edge of the purely volcanic area, indicates a north and south fault between the two, down-throwing on the west. Thus here as elsewhere round the margin of the Lake Country the volcanic rocks appear nearly everywhere to be faulted against the older Skiddaw Slates.

This is a very remarkable circumstance for which no explanation, as far as I am aware, has ever been offered. Were the bounding faults of normal character, we might suppose them to have been caused by the subsidence of the masses of ejected material, on the removal of the elastic pressure which caused the eruptions, into the hollow formed underground by the ejection of so much matter. As the faults however are of very high hade, being what are now called "*thrusts*," this explanation is of no avail. I would here remark that hade, a miner's term, is always measured from the vertical; and that therefore thrusts, or faults making a small angle with a horizontal plane, are faults with a high hade, and not with a low hade, as they are often incorrectly termed.

BORROWDALE VOLCANIC SERIES.

We will now describe the volcanic rocks, beginning at the north where the lowest beds appear, and working our way southward to the higher member of the series. There is a good section of the lower beds exposed in the bold crags that form the northern end of the High Street range facing Ullswater. They consist of a series of bedded ashes and breccia, containing one or two beds of lava, all steadily dipping N.E. The rock is not well seen on the

moor immediately above the crags; but at the Knotts and Ordnance Station, 1,331 feet above sea-level on Whitestone Moor, there is a section in bedded ash and breccia dipping N.E. at 10° , and along with those beds a trap-like vesicular rock, which however could not be traced far. South of this, Brown Beck gives sections in cleaved and sometimes flint-like felspathic ash: but the rocks are so greatly weathered that it is difficult to make out much about them. The same remark may be made generally of the High Street range north of High Raise, and Bason and Laythwaite Crags, throughout the whole extent of which country, stretching for five or six miles in a N.N.E. direction, the rocks are intensely disintegrated. As far as can be made out they seem to consist of highly-altered felspathic ash, such as in a less-decomposed state forms the mountain spurs north of Riggindale.

Amongst these lower beds of ash and breccia we find a trap (lava) stretching across Sceugh from Butterwick Crag to Helton Dale, where it probably dies out, as it could not be traced further, and is very thin where last seen. This trap is cut off at Butterwick by the fault, which there brings up the Skiddaw Slate. Between Bampton and Scrogs Hall a trap appears south of the faulted inlier of Skiddaw Slate: this may be the same bed, as it lies on the strike of the other: it overlies coarse-bedded ash of a purple hue dipping W. by S. Above Scrog's Hall another bed of trap is seen. These beds appear to be cut off by a fault ranging W. by N. across the south side of Hows Moor. Amongst the ash beds underlying these lavas a boss of intrusive trap appears in Ireland Wood, south-west of Bampton. Above the lavas a long extent of obscure ground stretches from Hows Moor to Helton Dale; but at Kettle Crag, on Helton Dale Horse, there is a good section of rough and cleaved ash dipping S. by W. at 50° ; and again in the grains* of Helton-dale Beck cleaved beds of ash and breccia dipping S. by W. at 40° ; but the rocks are much weathered. South of this scarcely anything is to be seen till we reach Cordale.

Along Cordale Edge amid beds of rough ash there is a bed of lava; but though fragments of striped slate are lying about in plenty, it is impossible to see the dip: the trap is probably dipping steeply to the S.E. nearly with the slope of the hill; and such appears too to be the dip of the slates in the Sealhole quarry. In the grains above Sealhole we have the usual highly decomposed felspathic rocks, with one or two obscure trap-like portions; and in the lower part of the dale, near Moorahill, there are beds of rough ash dipping N.W. Crossing Willdale over a descending series, we come to a bed of lava west of Drybarrows, which is probably the equivalent of that on Hows Moor; and below it there are altered rough felspathic ashes, which form the craggy hills north of Low Hawes Water. Amongst these ashes there is a peculiar bomboidal bed, consisting of felsitic

* The term "grain" is applied to the feeders of a beck, or to the spot where two small streams unite.

nodules as big as one's fist : this bed may be seen in several places running south from Drybarrows, the strike there being north and south.

East of this horizon there is a complicated bit of mounded ground reaching from Drybarrows across Aika Hill to Burn Banks. This broken ground consists of inter-bedded traps and ashes, dislocated by several faults and traversed by two greenstone dykes. The traps are in places very vesicular. A fault and copper vein, which was once worked with but little success, crosses these beds in a W.S.W. direction, and forms the northern boundary of a massive compact trap of great thickness, which is thrown out of sight west of Colby by a N.N.W. fault. On the west side of this fault we have a great thickness of crystalline streaky rocks, trap-like in part, but weathering rough and in places showing by included fragments that they are highly-altered ash and breccia. These rocks range from Colby by Mile Craggs and across Measand Beck by the higher force to Lad and Laythwaite (pronounced Laythelt) Craggs. The beds are rolling with a general easterly dip; but owing to the steepness of the ground we have the lowest beds at the bottom. On Lad Crag the whole mass of rock is so intensely altered and trap-like that it is difficult at first to make any distinction between one part and another: but the compact rocks at the base are even more trap-like than the upper part, and careful search shows a vesicular band like the top of a lava below Sandhill Knots, and a regular breccia overlying trap to the west and south. Further on in the same direction we lose the upper intensely-altered rocks, but still have in its proper place a thick lava or two such beds: these range along the hillside below Laythwaite Craggs and under Bason Crag towards Whelter Bottom, where they appear to thin away entirely. The underlying beds are mere ordinary rough ash containing a well-marked set of nodular bands about nine feet thick, like that mentioned above (p. 17) as occurring south of Drybarrows. This bed can be traced from near Low Kop by Fordingdale Force, all along the face of Bason Crag and Whelter Crag to Hanging Stones, where it is faulted and lost to sight; but it or a similar bed is found again in Randale Beck, ten chains below the sheepfold, whence it can be traced for some distance across the moor in a band fifteen yards wide. A similar bed is seen in one place ten chains above the sheepfold. Here some of the nodules are six inches long. The same or a similar bed, forty feet thick, is found cropping out among the well-bedded, but altered, felspathic ashes that form the north side of Riggindale; and lastly it is seen in two beds just below Kidsty Pike. It has been traced for a distance of three miles nearly continuously, and thus affords a valuable clue to the run of rocks. I may remark, as an interesting fact, that a precisely similar nodular or bomboidal bed is to be found in North Wales associated with the felstones of Y-Tryfan, as well as in other places. This bed, easily distinguishable and unique in character among the ashes and felstones of the district, I have found at intervals from Y-Tryfan by Gallt y Gogo to the

crags above Cwm Ffynnon. A similar band or bands is to be seen on Castell-y-Gwynt and on the spur of Y-Glyder-fawr that runs towards Gorphwysfa at the top of Llanberis Pass.*

Since the above account of the Mardale nodular band was written eighteen years ago, I have seen an interesting description of nodular Rhyolites by Mr. A. Harker in his Essay on the Bala Volcanic Series of Caernarvonshire, to which I must refer for a fuller account of such bomboidal beds. Not having had an opportunity of re-examining the Mardale rocks since 1876, I will only say that the nodular bands seemed to be ashes rather than lavas.

The rocks whose trend has thus been pointed out by the course of the nodular band, consist of rough, massive, bedded and altered felspathic ashes with a few beds of lava: the upper part of the series is the least altered, while the lower beds among which the traps occur are the most so: thus the Whelter Crags are ordinary rough and bedded ash in massive beds, while the lower rocks that form the spur south of Hanging Stones, from the 1,500 contour to Birks Crag, are altered felspathic ashes. Similar rocks range along Kidsty Howes to the head of Riggindale.

Below Birks Crag we find, extending down to the beck, alterations of more and less altered rocks with two chief beds of trap, the dip being about 10° to the N.N.W. Several grey dykes, generally trending N.E. and S.W., cross the Whelter Crags, and one granite dyke runs from near High Whelter in a W.S.W. direction. North of Whelter, Knotts, which consist of the highly altered felspathic ash, there occurs a mass of trap-like rock. This rock has in places very indefinite limits and is much mixed up with ash, so that it is probably not a lava, but either an extremely-altered portion of the ash or an intrusive trap.

We have now carried our description of the rocks up the north side of Riggindale to the dale head. Here rolling beds of coarse and massive ash are found circling round by Twopenny Crag, the Straits, Short Stile and Hause Crag to Long Stile. A trap, repeated several times by faults, with a beautiful vesicular top, is found among the bedded ashes that form Long Stile. Lower down, rough ash rudely cleaved, and blue compact altered rocks form Rough Crag; and at the eastern end of the Rigg there are bedded ashes and slates with traps. The ground is broken by faults and the dips are high to the south-east.

One of the traps associated with this set of beds is found between Blea Water Beck and Small Water to be in parts well cleaved: this is noteworthy as being unusual in traps in this district. Amongst these beds also two columnar traps are conspicuous, running up to the face of Harter Fell.

The rocks at the head of Mardale form a broken anticlinal; thus the bedded ash, breccia, and lavas of Harter Fell and Small Water dip S.E. at angles ranging from 20° to 70° ; while the similar bedded ash and lavas of Blea Water and High Street dip

* See also Ramsay, Geol. N. Wales, Ed. 2, p. 132.

N.W. at 20° to 50° . These beds are probably a repetition by faulting and rolling of the Small Water and Harter Fell rocks: they both consist of well-bedded rough ash and breccia and contain bands of fine slate; and in both are found two columnar traps.

This brings us to the southern limit of the map. Of the adjoining country on the south suffice it to say that the general sequence of the beds from north to south is as follows:—Altered ash and trap (probably a repetition of the rocks on the north face of Harter Fell), cleaved ash, massive rough ash, and fine slates which have been worked in Mosedale and Wrengill, and at Kentmere opposite the reservoir house. The slates are overlaid by a well-marked hornstone trap, which I have traced from Steel Rigg in Kentmere, to Little Mosedale, where it forms the crag known as Brunt Tongue. Over this there comes a great thickness of rough ash and breccia, rudely cleaved, with bands of finer slate and some trap-like beds, the upper part being much altered. This is succeeded by the Coniston Limestone with its associated pink felstone.

We have now described the country north and west of Mardale; and there remains to be described the country between Mardale and the Skiddaw Slate area of the River Lowther. This can be conveniently divided into two portions: first, the country between Hawes Water and Swindale; and secondly, that between Swindale and the Shap Granite.

The Country between Hawes Water and Swindale.—That the volcanic rocks at the north-east end of this area are brought against the Skiddaw Slates by faults, is shown by the strike of interbedded ash and trap on Rosgill Moor. The trap is a compact blue rock: and the thick bed of ash in Frith Wood is coarse and brecciated. The course of Hawes Water Beck below Thornthwaite Hall is occupied by a compact blue trap similar to that on Rosgill Moor: its strike is not apparent, but judging from the run of some thin lava flows amid the overlying ashes it is probably from N.W. to S.E.

The greater part of Naddle Low Forest is occupied by rough ash and breccia having a general dip to the S.W. as shown by some seams of bedded ash, which contain one or two thin bands of trap. These beds, which seem to be cut off by a fault, are succeeded by compact trap, which forms the hillside at the south-east end of Naddle Forest. A similar trap occurs in the valley-bottom in the High Forest: but it has a well-marked vesicular top, and is regularly overlaid by bedded ash inclined at angles of 15° to 40° towards the N.W. or W.N.W. The beds throughout the rest of Naddle Forest have a similar strike. These bedded ashes and breccias are succeeded on the west side of Naddle by a remarkable dolerite, porphyritic in parts, and containing much augite, the line of junction being marked by a vesicular band. The dolerite forms the crags overhanging Hawes Water, the most conspicuous of which lying due east of the straits is called Wallow Crag. From the mineralogical

resemblance of the rocks there is every reason to believe that this is the same trap as that which occurs on the north sides of Hawes Water near Colby and Measand. There the trap is associated with highly-altered rocks; and here one finds along the line of crags that mark its outcrop, many transverse fissures on the sides of which the rock has a very ashy look. I confess that the rock looked to me more like an intrusive or intensely-altered rock than a lava, but the Measand rock was considered to be a lava. We were not able to trace the rock all the way down to Hawes Water; for the hillside beneath the crags is much obscured by fallen blocks, and north-eastward the trap seems to end off abruptly along a north-west line. I may remark that the rocks between Hugh's Laithes Pike and Wallow Crag are highly altered.

A little south of the Ordnance Station 1427 in the High Forest, the dolerite is cut off by a fault, south of which bedded and more or less altered ashes occupy the whole space from Powleys Hill to Hawes Water. Above these ashes we find in Guerness Wood a trap which at its south-east end is nearly throughout highly vesicular. It is overlaid by breccia and rough ash.

Along Mardale Banks the beds which have hitherto had a pretty persistent north-west dip, begin to undulate; and at length, as may be seen near the footpath across Mardale Common, the dip is S.E. at high angles of 40° , 50° , 60° , &c. The rocks along Mardale Banks are nearly all very rough ash and breccia with a band of well-bedded ash in the upper part. Over these comes a bed of trap which is in parts highly vesicular, like the bed in Guerness, to which it corresponds in position. This trap cannot be traced in a north-easterly direction beyond a north and south line of break, which is marked by a nearly continuous feature from Naddle to Mardale Common. This fault is crossed by another coincident with a copper-vein along Guerness Gill. The resulting displacement is probably of no great amount, as a trap occurs on the north-east side of the faults very nearly on the previous line of strike. This rock is well seen at Woof Crag and south thereof.

East of Woof Crag there is an exposure of bedded ash dipping west at 25° with trap on both sides of it; but the general dip appears to be south-east from Hare Shaw to Mullender. The lower beds, which from Hare Shaw to Powleys Hill consist of altered felspathic ash weathering white, like those along the north side of Riggindale, thus crop out along the top of the hill and north thereof, while the slope towards Swindale is occupied by the overlying traps and bedded ashes. These latter do not however extend all the way down the slope into the valley-bottom; but appear to be cut off by a strike fault, which brings in the overlying rocks consisting of well-bedded ash. This fault is probably part of a fracture which crosses Mardale near Grove Brae, where vein-stuff is seen in the Grove, and which, ranging along the north side of Mardale Green, cuts off the traps there and extends past Small Water and north of Nan Bield into Kentmere.

The well-bedded ashes (mentioned above) are well seen dipping south at angles of from 15° to 90° along the hillside above

Swindale Head as far as Selside End. Here the bedded ash is succeeded by rough ash and breccia that show but scant trace of bedding. These rough rocks, which form the Blake Dods, are found, on following the normal south-westerly strike, to become a blue altered rock in Hop Gill, west of Selside Pike, and along Branstreet. The rough ash of Blake Dods is succeeded by fine pale cleaved ash, which forms the crags known as Black Bells and Black Wood, above Dod Bottom.

The Country between Swindale and the Granite Area.—We will now describe the country east of Swindale.

The lowest beds seen south of the Mullender fault are bedded ash and breccia in the stream near Truss Gap. These are succeeded upwards by the following series: fine splintery ash, false-bedded; a compact rock of doubtful nature; well-bedded and rough ash; massive breccia, forming Outlaw and Grouther Crags and Waite Howes; alternations of fine and rough and well-bedded ash, shown south-west of Blea Moss; and a set of inter-bedded traps seen below Black Crag and Glede Howe. The traps cannot be satisfactorily traced far west of Black Crag. They are succeeded by a thick mass of rough ash and breccia, which is well seen along the crest of the hill from Black Crag to Willy Winder Hill. Similar masses of rough ash and breccia, with here and there some bedded portions, partly broken by faults, extend across the country from Swindale Common by Fewling Stones to above the A of the word SHAP (on the six-inch map), where they are cut off by a fault bringing up the traps of Ralfland.

From Hobgrumble Gill to Willy Winder Hill these breccias are overlaid by a dark compact, partly crystalline, trap-like rock, which from its behaviour appears to be highly-altered rough ash: it ends abruptly in both directions against unaltered beds, but whether along faults or master-joints it is difficult to say. The trap-like rock is over-laid by the rough ash of High Weather Howe: this by a peculiar fine compact, partly-bedded, rock which weathers white; and this by a second set of rough ashes succeeded by a thick mass of cleaved ash, which contains the beds of fine slate that have been wrought in Mosedale, in Wrengill, at the head of Long Sleddale, and in Kentmere. Similar cleaved ashes are found on the strike of these in the Lowther Valley at Crags Mill and Kemphow; but considering the proximity of the Skiddaw Slate, these are probably a lower set brought up by an extension of the north-and-south fault which brings the Skiddaw Slates against the traps of Ralfland. These traps are of dark compact rock, and they probably correspond to the similar traps on Rosgill Moor.

The cleaved ash containing workable slate, mentioned above, is succeeded by a thick set of rough ashes and breccias. These are the beds which around the granite are converted into a dark compact porcellaneous rock.

There are several dykes of microgranite or quartz-felsite, among these altered rocks, pointing towards the granitic area, and at the

south edge of the map a dyke of fine-grained grey granite has been traced for nearly a mile among the unaltered rocks.

J. R. D.

MICROSCOPIC STRUCTURE OF SOME OF THE ROCKS IN THE AREA EAST OF THE HIGH STREET RANGE.

A. CONTEMPORANEOUS IGNEOUS ROCKS.

1. *Lavas*.

Porphyritic Dolerite, Wallow (Walla) Crag, Haweswater.
6 in., Sh. 13.

Lithological.—Fine mottled-looking porphyritic rock, with pale green felspar and dark augitic matter.

Microscopical. Specimen *A*.—Largely made up of augite in irregular plates, and showing fine colours in polarized light. Intermediate parts mostly filled up with highly altered felspar. Small garnets are present.

Specimen *B*.—A rather coarsely crystalline mixture of plagioclase felspar and altered augite, with a great deal of diffused calcareous matter and some quartz. Apparently very little magnetite, but black patches of an irony mineral are frequent in parts.

[The rocks from Wallow Crag (E. 2 and 24) have the microscopic aspect of sills, although the appearances are not absolutely inconsistent with their occurrence as very thick lava-streams. In the best preserved example the structure is ophitic, but there is a very small quantity of a second generation of felspar in prisms and granules between the ophitic patches. Plates of augite in various stages of conversion into uralite, enclose large crystals of plagioclase, which have usually undergone a certain amount of new growth at their edges, and this seems to consist of the same substance, formed at the same time as the prisms just mentioned. There is secondary calcite and quartz, the latter occasionally penetrated by actinolite needles.—W. W. W.]

Three specimens taken from what is probably the same lava bed, upon the other side of the lake, show the following structure.

Specimen *C*.—Altered felspar crystals of medium size, with chloritic and serpentinous pseudomorphs, and quartz in small grains. The chlorite is often crystallized in fan-like groups.

Specimen *D*.—Coarse crystalline mixture of felspar—much of which is certainly plagioclase—and augite, with black titaniferous iron-oxide and pyrites. Fine fans of chlorite crystals.

Specimen *E*.—Much the same as the last, the minerals all much altered.

[The three specimens from Measand Beck (E. 43, 45, 46) to which this refers belong to the same rock-type as Wallow Crag. Sufficient augite is left to show that it is the mineral which has been converted into uralite, and of this there is a great deal in the slide. Hypersthene is probably present in 43, but absent from

the others. The structure is like that described from Wallow Crag. A good deal of white mica has grown inside the feldspars, and new feldspar growth has taken place at their edges. —W. W. W.]

Lava—cleaved—Aika Hill. 6 in., Sh. 13.

Lithological.—This bed occurs amongst cleaved ashes upon Aika Hill, just north of the foot of Haweswater. It is of a green colour and micro-porphyrific; being cleaved it has rather an ashy aspect.

Microscopical.—Minute feldspar crystalline base, the space between the needles being filled with chlorite and scattered magnetite. Larger feldspar crystals porphyritically embedded and much altered. A good deal of diffused calcareous matter. No indications of the cleaved structure in the slice examined.

[There is no porphyritic augite in the rock E. 6—the porphyritic feldspars are of two kinds, larger and smaller laths; the base is minute and microlithic; there are iron-ores in crystals and in fine dust with calcite and epidote.—W. W. W.]

Lava (of Diabasic character). E. 7, Brunt Tongue. 6 in., Sh. 20.

E. 9, S.E. of Brown Howe. 6 in., Sh. 20.

Lithological.—Very compact and flinty-looking. Effervesces slightly with acids.

Microscopical.—No definite crystalline but a somewhat granular base of a brownish colour, with many small magnetite grains and small porphyritically embedded crystals of feldspar and augite (?), much altered. A great deal of diffused chlorite, the small grains of this mineral possibly representing augite.

[Two specimens (E. 15, 17) taken from the trap-like bed at the head of Long Sleddale are very similar in microscopic character to those just described, but in one of these examples the embedded crystals all have a definite set in one direction, and in both some of the small brightly coloured (under polarized light) crystals appear to be epidote.—W. W. W.]

Lava (of Diabasic character). S.S.W. of Brown Howe, Mardale. 6 in., Sh. 20.

Lithological.—Very compact flinty-looking rock.

Microscopical.—The base seems to be glassy, with yellowish doubly-refracting particles, which may represent augite grains. Magnetite in small grains. Feldspar in crystals showing much alteration, but feldspar needles absent.

Lava (cleaved Diabase). N. of Small Water. 6 in., Sh. 20.

Lithological.—The cleaved character gives an ashy appearance. Effervesces with acids.

Microscopical.—Minutely chloritic-granular base much impregnated with carbonate of lime. Crystals of feldspar drawn out in direction of the cleavage-planes. Magnetite and pyrites (?) present.

Lava (of Diabasic character). Thorny Knott. 6 in., Sh. 20.

Lithological.—Compact blue base with green spots.

Microscopical.—Only traces of crystalline structure to be seen in the base. Chlorite disseminated and serpentine as pseudomorphic matter. Very little unaltered augite. Magnetite. Felspar, much altered.

[The six specimens above described E. 7, 9, 15, 17, 40, 52 have many characters in common. In containing no other porphyritic constituent than plagioclase felspar they agree with the specimen from Aika Hill, but they differ in the paucity and smallness of these crystals. The groundmass also is excessively minute, so that a high power is necessary to demonstrate that it is chiefly made up of minute microlites of felspar with calcite and chlorite. Iron-ores are not plentiful, but most of the rocks contain epidote. A great deal of sericite is developed along the cleavage direction in the rock from north of Small Water. That from Thorny Knott (E. 51) contains porphyritic felspar and bastite pseudomorphs of hypersthene grouped together and set in a fine base of felspar microlites and augite grains.—W. W. W.]

(2.) Volcanic Ashes (highly-altered examples).

Highly altered Ash. The Knott. 6 in., Sh. 20.

Lithological.—Crumbling mottled, felsitic base, weathering of a light colour.

Microscopical.—Finely granular and chloritic base with a flowing structure among and around crystals and fragments of crystals, many of the latter lying in the direction of the flowing lines. Character generally felsitic.

[This rock (E. 175) has been subjected to considerable crushing. There are porphyritic crystals of orthoclase and plagioclase often faulted and crushed, a few of hornblende, but none of quartz, set in a cryptocrystalline matrix. It is a crushed felsite and is not unlikely to occur here as a dyke.—W. W. W.]

Concretionary bed in altered Ash. Kidsty Pike. 6 in., Sh. 20.

Lithological.—Egg-shaped nodules but with no definite internal structure. Weathering white round the edges.

Microscopical.—General felsitic structure, with a great deal of chlorite.

[This rock (E. 172) is almost certainly a nodular felsite and is probably continuous with that from Threshthwaite Mouth (E. 163); the latter has an exceedingly minute groundmass in which felspar microlites and sericite can be distinguished. Embedded in this are traces of felspars, chlorite pseudomorphs, quartz grains, and some sphene. The nodules are white exteriorly, and get gradually darker towards their interior, which is loaded with chlorite. The nodules are broken up and have angular edges in the rock.—W. W. W.]

Altered ash at junction with Shap Granite. 6 in., Sh. 21.

(a.) Sleddale Pike.

(b.) Below Wasdale Pike.

Lithological.—(a) is very compact and with a purplish-grey micaceous base: (b) is a fine-grained grey micaceous rock.

Microscopical.—Base is felsitic, with numerous minute mica-flakes and grains of a yellowish-green colour and sometimes drawn out in lines (as in (a), cleavage?). Accompanying these are many minute black spots which appear to be magnetite, though sometimes they have an almost circular outline; and a great number of small light green prisms lie scattered about. Under a power of a $\frac{1}{4}$ -inch the base shows faint lines like the outline of a tessellated pavement, and under crossed nicols these lines are seen to belong to a semi-crystalline felsitic structure, as if the quartz and felspar had not completely separated from each other.

(3.) *Ashy and Gritty Beds in the Skiddaw Slates.*

E. 192, 193, 194, 808, 809, 810. Interstratifications with Slate. 6 in., Sh. 13.

Lithological.—Very sedimentary in appearance, but with an ashy-looking grain in parts.

Microscopical.—Absence of crystalline particles; all decidedly granular, with the small fragments generally irregular in their shape. Calcspar occurs disseminated and in strings.

Gritty Calcareous Ash. Rosgill Wood, below the outcrop of the Carboniferous Limestone. E. 191. 6 in., Sh. 14.

Lithological.—Very trap-like in general appearance, compact, and grey-blue in colour.

Microscopical.—No trace of crystalline structure discernible. Small quartz and other fragments. Irregular vesicles and cracks filled with calcite. Under crossed nicols the ground is dark with scattered points of light.

B. INTRUSIVE ROCKS.

Dolerite (E. 92) amongst Skiddaw Slates. Tullyhouse Gill, Thornthwaite. 6 in., Sh. 13.

Lithological.—Fine, grey, slightly speckled rock, effervescing with acids.

Microscopical.—Fine crystalline mixture of plagioclase felspar in large needle-form crystals, and a slightly pleochroic mineral which may be hornblende, though it is very like augite in many places. There is also a good deal of a dark green blotchy mineral and iron-pyrites. Calcspar in interstices.

[There is sufficient augite left to show that the structure was originally ophitic and that the rest of this mineral is replaced by calcite and chlorite; the iron-ores are almost entirely replaced by leucoxene.—W. W. W.]

Diabase (E. 91) (quartzose). East side of Aika Hill.
6 in., Sh. 13.

Lithological. — Fine-grained grey, crystalline base, with pyrites.

Microscopical. — Crystalline mesh-work of short, squarish feldspar and quartz crystals and chlorite, with pyrites, and diffused calcite.

[E. 91 is a diabase containing lath-shaped feldspars often fresh, twinned, and zoned, and large crystals of ilmenite much altered in places to leucoxene; these are set in calcite, chlorite, and secondary quartz, so that it is not possible to make out the original structure, once doubtless ophitic. The specimen E. 79 from Tailbert (14 S.W.) is intensely altered. There are relics of augite crystals which appear to have been twinned but are now in the form of chlorite, traces of porphyritic feldspars and possibly of hypersthene, in a highly-altered matrix containing secondary quartz, some feldspar, and much calcite with a few garnets.—W. W. W.]

Quartz Felsite (E. 135). Fairy Crag, Crag Bridge. 6 in., Sh. 14.

Microscopical. — In the slices examined the base of this rock is felsitic, being composed largely of quartz in small grains and a great quantity of the yellowish-green chloritic mineral frequently crystallized in radiate and fan-shaped groups. Crystallized feldspar seems rare, while brown mica is present in long flakes, and crystals of quartz are here and there porphyritically embedded. Besides these minerals a little hornblende may also be present. There are some excellent examples of actively-moving bubbles in the liquid cavities of the quartz.

Quartz Felsite (E. 138). Near Aaron's Bield, N. of Brown Howe. 6 in., Sh. 20.

This is a small patch occurring among highly-altered ash-rocks. The character of the neighbouring rocks would suggest that this may be only an extreme of alteration.

Lithological. — Compact crystalline base with small white feldspar crystals, and some crystals of quartz.

Microscopic. — Felsitic base with small quartz crystals enclosing portions of base [and surrounded by resorption halos], short green dichroic mica fibres, and a few large feldspar crystals, some of which are plagioclase [generally aggregated into groups]. Here also a great deal of chloritic mineral, crystallized in fan-shaped groups, is diffused throughout the mass.

Porphyritic Quartz Felsite Dyke. River Lowther, near New Ing. 6 in., Sh. 21.

Lithological. — Very compact base containing many mica flakes, quartz, and large pinkish feldspar crystals.

Microscopical.—Felsitic base, containing large crystals of felspar, both orthoclase and plagioclase, showing good crystalline forms. There are also many flakes of brown mica much altered into the less pleochroic green variety; and blebs of quartz.

[The porphyritic crystals in this rock resemble those of the Shap Fell granite. The only one cut by the slide is a microcline pegmatitically intergrown with quartz. There is much plagioclase in well-developed crystals enclosing mica flakes and itself at times enclosed, but in a decomposed condition, in later orthoclase. The rock has the characters of apophyses of the Shap Granite.—W. W. W.]

*Shap Granite.** Wasdale Crag. 6 in., Sh. 21.

Lithological.—Coarsely crystalline granite with large red felspar crystals, dark mica, and some pyrites.

Microscopical.—Coarsely crystalline quartz with a tendency to definite crystalline form in some parts; liquid cavities in the quartz much in lines but not very numerous. Felspar is plagioclase, often showing the richest blue colour in polarized light, with beautiful banding. Large portions of these crystals—especially of the interior—are converted into an opaque granular substance. The mica is brown, sometimes showing crystalline form, strongly dichroic, and in parts converted into a green alteration-product, less dichroic.

In an example of this granite at its junction with the altered volcanic rocks, the general matrix of the granite is more quartz-felsitic.

J. C. W.

* For a full account of this granite see paper by A. Harker and J. E. Marr on "The Shap Granite and Associated Rocks," in the Quart. Journ. Geol. Soc., vol. xlvii. p. 266.

CHAPTER IV.

LOWER AND UPPER SILURIAN.

Area around Knock.

General Introduction.

Physical Characteristics.—The area occupied by the Lower Palæozoic Rocks in the vicinity of Knock is the central portion of a long and narrow strip of strata older than those around, which extends, as a faulted inlier, from near Roman Fell on the south-east to about a mile to the north of Melmerby in the opposite direction, a distance of about fifteen miles. The physical aspect of much of this area is striking, and is specially characteristic. It consists of a chain of conical and rounded hills, or Pikes, which stand like buttresses between the steep edge of the great upland area formed by the Carboniferous rocks on the north-east, and the undulating lowlands formed by the Permian and Triassic rocks of Edenside on the south-west.

General Geological Features.—The geological sections around Knock Pike are generally, and rightly, regarded as affording the most accessible and most easily-studied exposures in the district; and on this account Knock Gill (or Swindale Beck) and Knock Pike are much more frequently visited by geologists than any part of the areas adjoining. Moreover, it has long been recognised that the geological structure of this small area affords information of considerable importance in the interpretation of some otherwise obscure geological problems presented by the rocks of the Lake District and elsewhere. For this and other reasons the area specially under notice calls for a fuller description than its mere superficial extent would at first sight appear to warrant.

In order that the student may be able to fully appreciate the special features of these rocks, it is desirable to take in review here the broader features of the geology of the rocks of the same age in the Lake District, so that the points of agreement or of difference between the history of the rocks in the two areas, may be brought into sufficient prominence to render the special features of the geology of this region clearer than would be possible by other modes of treatment.

The succession of Silurian Rocks in the Lake District, their thickness, and their equivalents in Wales are as follows:—

—	Lake District.	Equivalent Strata in Wales.	Thickness in Feet.
Upper Silurian.	Kirkby-Moor Flags - Bannisdale Slates - Coniston Flags and Grits - Stockdale Shales or Pale Slates Graptolitic Mudstones -	Upper Ludlow - Ludlow-Wenlock - Lower Wenlock - Upper Llandovery - Lower Llandovery	13,000 to 14,000.

—	Lake District.	Equivalent Strata in Wales.	Thickness in Feet.
Lower Silurian and Cambrian.	Coniston Limestone Series, including some Volcanic Rocks.	Bala -	12,000
	Borrowdale Volcanic Series Skiddaw Slates -	Llandeilo to Arenig - Arenig to Middle Cambrian.	
			10,000

For purposes of comparison with the rocks of the same age occurring in the Pennine area, it will suffice in the preliminary remarks to notice such of the more salient characteristics of each as is necessary for the purpose in view ; and, in doing so, it will be more convenient to notice them in ascending order.

In regard to the Skiddaw Slates, which type of rocks is extensively developed in the Pennine area, the departure from the type seen in the district around Keswick is not of sufficient importance to call for any special remark. In the case, however, of the succeeding volcanic rocks of the Borrowdale Series, differences of much importance in the present connexion are very apparent on comparison of the types prevailing in the two areas. In the central part of the Lake District the Borrowdale Volcanic Rocks consist of a vast pile of tuffs, agglomerates, and lavas, which occur without any interstratified material to which a sedimentary origin can safely be attributed. Hence the volcanic group as a whole, is generally regarded as having had a mainly sub-aerial origin. But in various places on the outskirts of the Lake District, rocks of distinctly sedimentary origin occur interstratified with volcanic rocks, in such a manner as to leave no doubt that part at least of these cases are those of strata which accumulated on the seaward flanks of the old volcanic area. Hence the eastern margin of the present Lake District happens nearly to coincide with the zone where the volcanic type of accumulations begins to pass into the marine type proper to areas outside the zone of eruption. This fact is of much importance in the present connexion, because, in the area more particularly under notice, there occur repeated alternations of sedimentary rocks of the Skiddaw Slate type with grits and greywackes containing a variable, but often large, percentage of fragmentary material of volcanic origin. These are unaccompanied, as a rule, by lava flows. The fossils which occur in association with this mixed type of strata show that the rocks pertain to a higher horizon than the Skiddaw Slates properly so called, and that they belong to the Upper Arenigs. We may therefore safely conclude that the area specially under notice remained through at least all the earlier part of the period, when the Borrowdale type of rocks was being formed, so far from the centres of eruption, that few or no lavas reached as far out to sea, and that it was only during the more violent paroxysms of eruption that volcanic ejectamenta were shot

forth to sufficient distances to reach this point, and thus to form any noticeable proportion of the material accumulating here upon the sea-bottom. In other words, the volcanic rocks of the Borrowdale type are here represented by rocks of a different character, which are mainly of sedimentary origin. There is sufficient evidence to show that the thickness of rock of this type amounts to several thousands of feet. It will be convenient to adopt for this the name Milburn Group, from the locality near which it is most typically developed and is best seen.

Returning to the further comparison of the two areas: we find that the highest members of the volcanic series in the Lake District belong to petrographical types different from those prevailing in the older and lower part. In place of the andesites and basalts of the Borrowdale type proper, the higher volcanic rocks are, very generally, trachytes, or even liparites, together with their respective tuffs. The same is the case in the Pennine area, where these rocks are thicker and are better developed than they are in the Lake District. Acid and sub-acid lavas as a rule do not travel far from the vents; we therefore may conclude that, during the later part of the great volcanic episode in the history of the Lake District rocks, the centres of eruption did not coincide with the older vents, but were nearer where the Pennine area is now. This will have to be steadily borne in mind, otherwise the relationship of the older volcanic set in the Pennine area to the volcanic rocks that succeeded these cannot be fully comprehended.

In the Lake District there is evidence of a certain amount of disturbance, followed by extensive denudation, in the period following the last eruption of the volcanoes of Bala age. So far as the evidence enables us to judge no such disturbance and denudation occurred in the Pennine area. On the contrary there is clearly a passage from the volcanic type of rocks of this age upwards into the succeeding Coniston Limestone Series. Then, after a long interval, if we may judge by the palæontological evidence, the various members of the Upper Silurian Series were deposited—beginning with the Graptolitic Mudstones, and going on through the Pale Slates, the Coniston Flags and Grits, and the rest of the vast pile of rocks of sedimentary origin which belong to the Lake District type of this series.

Between the close of the Silurian period and the commencement of the next period of which any record is left here, followed an interval of time, which, if one may judge by the physical and biological changes which took place in the meantime, must have been one of enormous length. During this long interval all the older Palæozoic Rocks were disturbed and contorted, were affected by cleavage, and were dislocated by faults—probably as a result of many earth-movements repeated at intervals. The rocks too were subjected to extensive denudation, probably acting at several different periods; so that the final result was that the next formation represented here—the Upper Old Red Sandstone—lies upon the upturned and denuded edges of strata whose total thickness in Westmorland can be shown to exceed *five miles*. As a

consequence of the violent unconformity between the Upper Old Red Sandstone and the older Palæozoic Rocks, the newer series may be seen reposing in an almost undisturbed position upon representatives of every member of the older series, which have been contorted, cleaved, and extensively faulted, long prior to the deposition of the Carboniferous rocks. These, in many cases, extend, with relatively unimportant dislocations, across the prior formed disruptions which affect the older series.

A second series of disturbances, following the close of the Carboniferous Period, and preceding the formation of the Permo-Triassic rocks, in turn affected the Carboniferous strata, and gave rise to another set of faults, whose directions, in many cases, followed those of the Pre-Carboniferous lines of fracture. Afterwards followed another period of prolonged exposure to sub-aerial waste, during which between ten or twelve thousand feet of the prior-formed rocks were denuded away. Upon the surface thus formed were deposited the Permo-Triassic series of strata, followed, in all probability, by other rocks of Neozoic age.

Lastly came the period or periods of upheaval to which the broader features of the existing surface are directly or indirectly due; and during which the differential movements accompanying the upheaval were locally repeated yet again over the older lines of fault.

A thorough comprehension of this complicated series of geological events is absolutely necessary for the correct understanding of the geology of the district under notice, and especially for the comprehension of the effects resulting from the complicated series of disturbances known as the Pennine Faults, which we are now prepared to consider in a little more detail.

Pennine Faults.—Considered first in a broad and very general way the Pennine Faults near Knock may be regarded as a series of dislocations, ranging in a general north-westerly direction, whose effect has been to disturb a large tract of Carboniferous (and newer) rocks, and to elevate these on the north-east side of the plane of fracture to a position higher by many thousand feet than that of their equivalent strata, which on the opposite side of the faults lie buried deep beneath the surface. The actual result is much more complicated than this, owing to the fact that there are many independent lines of fracture, whose several directions and amounts of downthrow cannot be adequately dealt with in a general description. The more obvious fault is that which, in this particular area, brings into vertical contact the Triassic rocks against the strata of Silurian age. This fault is the chief boundary-fault, and may conveniently be referred to as the Outer Pennine Fault. Its exact position at the surface cannot everywhere be determined with precision; but in the course of the small stream flowing southwards a few hundred yards to the east of the village of Knock, soft red sandstone belonging to the Trias (St. Bees Sandstone) may be seen in the course of the stream for about three hundred yards above the footbridge and

ford between Knock and Far Close. At the point mentioned these red sandstones suddenly terminate against an outcrop of dark blue, finely-striped mudstones, whose fossils show that they represent the division of the Wenlock strata known as the Coniston Flags.

The Inner Pennine Fault, or that which bounds the Silurian area on the opposite or north-east side, is one of much less important dimensions. The range is just outside of the limit of the map under notice, and it does not therefore call for further reference here.

Between the two boundary-faults occur others of important dimensions, whose effects are chiefly confined to the older Palæozoic rock. The more important of these may conveniently be referred to as the Middle Pennine Faults. These latter will be described in detail in their proper place.

Age of the Disturbances.—As will be gathered from the introductory remarks it is not easy to fix, even approximately, the date of the chief disturbances. There can be no doubt that, so far as the faults are concerned, they acted as planes of weakness again and again during several geological periods. Some, probably the majority, are certainly of pre-Carboniferous age; but it can easily be shown that, once a fault has arisen, newer rocks at first deposited continuously across its outcrop, have been dislocated over the older fractures, sometimes in directions of movement the opposite of the original.

History of the Present Configuration.—There is no direct evidence to show what the form of the surface was like at any of the earlier periods in its history; nor can we point with any confidence to any existing surface-feature which dates back far into the past. All that can be stated with any certainty is that at some period subsequent to the last great disturbances, denudation, acting upon the exposed parts of the upheaved mass of rocks, first removed all the superincumbent strata down to the last vestiges of the Carboniferous rocks, and then, out of the broken and plicated fragments of the pro-Carboniferous floor so exposed, has, in time, shaped out the various depressions, leaving as undestroyed remainders between these depressions the masses of rock which now form the Pikes and other foot-hills which characterise the scenery of these parts.

As might be expected in the case of rocks which are so ancient, and which have been exposed to repeated and prolonged disturbance of many kinds, those of the area under notice present even more complicated problems than do their equivalent strata in the Lake District. Indeed some parts of the area are so much fractured and dislocated by the numerous faults that one would be quite justified in speaking of it in general terms as a great mass of fault-breccia. Here and there, as in the part of the district specially referred to, some of the fragments are sufficiently extensive to furnish us with some clue to their geological position; but much of the remainder consists of little else than isolated

fragments of rocks belonging to widely-separated, and in many cases, little known, geological horizons. The rocks, too, are commonly devoid of fossils, and they present no lithological characters special to themselves. Add to these causes of uncertainty those arising from the fact that comparatively few exposures of rock occur, and it becomes evident that the geology of part, at least, of the area under notice must long remain in a state of more or less obscurity.

Prevalent dip.—If we disregard minor flexures and local variations of dip it is evident that the older Palæozoic rocks here have a prevailing inclination towards the south-south-west. In this respect the area under notice differs from the Lake District proper, as well as from the south of Scotland, in both of which the prevalent strike over large areas is east-north-easterly. On the other hand, the strike in the Pennine area agrees with that of the older rocks of the Howgill Fells and Craven, both of which areas lie to the south-south-east of this. In all three of these cases the dominant strike tends to be deflected from that prevailing in the Lake District and the south of Scotland, and to conform in direction to that of the larger faults. The dips on the whole are southerly in the Pennine area, so that the newer rocks are found in most cases nearest to the Outer Pennine Fault, while older beds, generally speaking, tend to rise to the surface as they are followed towards the north-west.

DETAILED DESCRIPTION OF THE ROCKS.

LOWER SILURIAN.

SKIDDAW SLATES.

In the absence of palæontological evidence the identification of zones in the Skiddaw Slates, and therefore of the exact geological horizon of the various fragmentary patches that occur here, must remain doubtful. All we can safely state regarding this question is that in and around the area under description occur strata lithologically similar to the Slates of Skiddaw and the neighbourhood of Keswick, and which may, therefore, be of about the same age. With these are associated other very similar rocks (the Milburn Group), which, on account both of their being interstratified with sub-marine volcanic rocks, and of their locally yielding an assemblage of graptolites and other fossils which pertain to Upper Arenig and Llandeilo horizons, are regarded as being of later date than the Skiddaw Slates properly so called.

The entire succession from above downwards appears to be—

- | | |
|--|--|
| 5. Milburn Group | } equivalents of the lower part of the |
| 4. Ellergill Beds | |
| } Borrowdale Series. | |
| 3. Upper Skiddaw Slates. | |
| 2. Watch Hill Grits (Arenig Grit). | |
| 1. Lower Skiddaw Slates and Grassmoor Grits. | |

Amongst the disturbed and faulted areas of these older Lower Silurian rocks in this neighbourhood the subdivision 4 is certainly and 3 is probably, represented; but there is no clear evidence to show that any subdivision older than these occurs within the north-eastern part of the area. Probably the oldest rocks here referable to the Skiddaw Slates occur in the Fell Pastures, a few hundred yards to the north-west of Sink Beck. Here they consist of dark grey flags and thin argillites, of the type usual on the higher horizons of the Skiddaw Slate. These strike north-westerly, and are traversed by cleavage-planes with an east-south-easterly direction.

CONISTON LIMESTONE SERIES.

As in the case of the Upper Silurian rocks, the section exposed in Knock Gill (or Swindale Beck) has long been celebrated as affording also one of the best exposures of the upper part of the Lower Silurian rocks. The highest member of the Coniston Limestone Series is represented here by an upper, thinner, series of shales and argillaceous limestones, and a lower, and thicker, series, consisting chiefly of calcareous shales. All these are well displayed in the course of Knock Gill, from a point a little short of a hundred yards below its junction with Small Burn, northwards for nearly four hundred yards in a direct line. The purely lithological division into two groups, which well enough serves the purpose in giving a general description of the rocks, has been shown by Messrs. Marr and Nicholson* to be inadequate on palæontological grounds. Viewing the various minor subdivisions of these beds in ascending order, we find, at the base, a bed of calcareous tuff, which appears to graduate both downward into the underlying volcanic rocks and upward into the overlying shales. This bed is not more than a few feet in thickness at the very most, and no fossils have been recorded from it. The next bed above consists of dark grey calcareous shales, partly affected by cleavage, and containing many calcareous concretions. This is the "*Discina-corona* bed" of Professors Harkness and Nicholson.† Messrs. Marr and Nicholson record from it:—‡

Beyrichia wilckensiana, Jones.

Primitia semicircularis, Jones and Hall.

Lingula tenuigranulata, McCoy.

Strophomena grandis, Sowerby.

Strata of the same general lithological character, but containing a different assemblage of fossils, overlie the *Discina-corona* bed. These are the Dufton Shales of Messrs. Harkness and Nicholson. The rocks are cleaved, and are, further, affected here by numerous minor disturbances; on this account it is difficult to form an exact estimate of their thickness. This is probably, however, considerably greater than that presented by the equivalent strata in the

* Quart. Journ. Geol. Soc., vol. xlvii. pp. 504-6.

† *Idem.*, vol. xxxiii. p. 463.

‡ *Idem.*, vol. xlv. p. 505.

Lake District. The outcrop measured in the line of the dip is nine hundred feet, which, if the dips can be trusted to average about fifty degrees, gives a thickness of between six and seven hundred feet. This estimate agrees fairly well with others made in the areas adjoining.

In regard to the correlation of these Dufton Shales with their supposed equivalents in the Lake District, Messrs. Marr and Nicholson write: "Their fauna is quite similar to that of the main division of the Coniston Limestone of the Lake District, so that whether we suppose that this is a more specially shaly base of the Coniston Limestone Series or an argillaceous representative of the whole of that series, we are fully persuaded that these Dufton Shales are of the age of the Coniston Limestone, and not an underlying deposit, as has been previously asserted." It is only fair to mention here that the correction of the error referred to is due to the work of the Geological Survey in the "early Seventies." The same authors have recorded from the Dufton Shales of this section the under-mentioned fossils:—*

Dicellograptus complanatus ?, *Lapw.*
Diplograptus socialis ?, *Lapw.*
Calymene senaria, *Conz.*
Cybele verrucosa, *Dalm.*
Illænus Bowmannii, *Salt.*
Phacops Brongniarti, *Portl.*
Remopleurides Colbii, *Portl.*

Beds appertaining to the lower part of this subdivision are also seen in the course of a small stream flowing southward midway between Knock Pike and Milburn Beck. Some exposures of the higher part of the same subdivision are also to be seen near the foot of Small Burn. There is another exposure in the roadway a few hundred yards south of the Hallsteads farmhouse.

At the junction of the Small Burn with Knock Gill (Swindale Beck) comes in the base of the higher and more calcareous member of the Coniston Limestone Series. This subdivision consists of well-bedded, dark blue, argillaceous, limestones with subordinate interstratifications of calcareous shales, which are often of a greenish-grey colour. Messrs. Marr and Nicholson refer to this subdivision as the "Staurocephalus Limestone." From the section at present under notice they have recorded (*op. cit.*) the following fossils:—

Echinosphærites arachnoideus, *Forbes.*
Turrilepas.
Acidaspis.
Illænus Bowmanni, *Salt.*
Lichas laciniatus, *Wahl.*
Phacops Jukesii, *Salt.*
Phillipsinella parabola, *Barr.?*
Staurocephalus globiceps, *Portl.*
Trinnucleus seticornis, *His.*
Orthoceras, *sp.*

* Quart. Journ. Geol. Soc., vol. xliv., p. 505. See also F. R. C. Reed, *Idem.*, vol. lii. p. 407.

Above the *Staurocephalus* Limestone occurs a small thickness of bluish calcareous shales, which have been correlated on palæontological grounds with the Ashgill Shales, the highest subdivision of the Coniston Limestone Series in the Lake District. From Knock Gill the authors above named record for this subdivision the following fossils :—

Phacops mucronatus?, *Brongn.*
Orthis biforata, *Schloth.*
 „ *elegantula*, *Dalm.*
 „ *protensa*, *Sow.*
Orthisina sp.
Strophomena siluriana, *Dav.*

These rocks are succeeded by some representatives of the Graptolitic Mudstones, the junction being, as before stated, probably coincident with a small fault, which cuts out the lower beds of the mudstones referred to.

VOLCANIC ROCKS OF KNOCK PIKE.

The relationship of the volcanic rocks of Knock Pike to the Coniston Limestone Series has already been shown to be one of perfect conformity—indeed the one may almost be said to pass into the other through intermediate strata of tuff mixed with calcareous clay. The mapping of these volcanic rocks has presented considerable difficulties, which are due partly to the fact that the rocks have evidently undergone a certain amount of change, which renders their subdivision in the field by no means as simple a matter as most of the published statements regarding them would lead one to believe. They have long been recognised by the Geological Survey as consisting of a series of acid or subacid volcanic rocks, partly of effusive and partly of fragmentary origin. But although it is by no means a difficult matter to select hand-specimens which both macroscopic and microscopic observations show plainly to be lavas, or tuffs, as the case may be, yet, in the field, the line between the one type and the other is often so ill-defined that it is practically impossible to lay it down in the customary manner upon the map. Part of this difficulty arises from the fact that the rocks commonly recognised as lavas certainly do include a variable, and, in some cases, rather high percentage of included fragments, and are, moreover, brecciated in a manner that may be due to the breaking up of hardened crusts through movements during consolidation. These features, together with the marked absence of vesicular or scoriaceous structure, the general absence of porphyritic crystals, and the strongly-marked banding (which may or may not be regarded as either fluxion-structure or bedding), make their resemblance to some of the altered tuffs of the Lake District so remarkable that the officers of the Survey hesitated for some time before coming to any definite conclusion regarding them. Closely associated with these banded felstones, and, indeed, inseparable from them, are beds manifestly of fragmentary origin, which have passed in the course of ages into compact and almost lava-like rocks. As

microscopic examination cannot be applied to a number of specimens sufficiently large to settle this question, the Geological Survey have for the present abandoned the attempt at separating the one type from the other, and have shown the whole of these felstones on the map by one colour.

The field-characters of the rocks, not already referred to, may be described in a few words. They consist of more or less well-banded felstones (some of which may conveniently be referred to as tuff-felstones) and lavas—prevalently salmon-coloured on the weathered surface (perhaps never as light coloured as true liparites generally are) and, upon fresh fractures, coloured of various tints ranging from cream colour through flesh-red, and to greys and greens of various shades. The marked absence of vesicular structure and the rare occurrence of any conspicuous development of porphyritic constituents have already been alluded to. Parts of the rock are very distinctly banded or ribboned, while a very-evident finer, wavy, structure prevails to such an extent as to have suggested to many observers an effusive origin for almost the whole of these rocks.

Good exposures of these rocks occur in the part of Knock Gill which may be described in general terms as lying to the south-east of the summit of Knock Pike. On the Pike itself, which consists exclusively of these banded felstones, the rocks are very well seen, especially on the slopes lying to the north-east and the east of the summit. They are much kaolinised in general; but the geologist will find little or no difficulty in making out the characters described above. Less weathered conditions of the same rock are to be found in the course of Knock Gill itself, and this section shows the various types of lithological structure prevailing in these felstones much better than the exposures on the Pike, and for this reason the section in the stream-course should be carefully examined by those who wish to study the whole of the facts.

Beds underlying the Knock Pike Felstones.—Where the greatest thickness of felstones is exposed here it may amount to about nine hundred feet. There appears to be some reason for believing that sub-acid volcanic rocks of the same general type as these continue downward to at least double that thickness, and that they, in their turn, overlie a series of sub-basic and basic lavas and tuffs. In the area specially under notice, however, no trace of any of these lower beds is to be found, because faults of considerable magnitude, referred to collectively as the Middle Pennine Faults, with a net result of a large downthrow to the south-west, bring strata much older in the series into direct contact with the Knock Pike Felstones. The effect of one of these faults can be easily studied in and around Knock Gill almost due east of the summit of the Pike. On one side of the zone where the great fault crosses the stream, ash-felstones and other volcanic rocks are clearly shown, while about a hundred yards or so farther up the Gill there appears an area of crushed shales of the ordinary Skiddaw-Slate type, which, on the west bank of the stream, give place to ashy grits of a type

quite unlike any of the rocks already noticed. The place of the fault itself can be marked down to within a few feet along the foot-path leading from the village of Knock through the Fell Pastures about three degrees south of east of the summit of the Pike. Here felstones of the Knock type are seen on one side of the zone, and on the other crushed shales of the Skiddaw-Slate type like the section seen in the Gill. The line of the fault nearly or quite coincides with the outcrop of a quartziferous minette dyke, to be noticed in more detail presently. A little farther up the stream, and close to the junction of Sink Beck with Knock Gill, there occurs an exposure of rocks of the type here referred to as the Milburn Group, and which have been already mentioned as the probable marine representatives of the older volcanic rocks of the Lake District. Here, and in general in this area, the rocks of the Milburn Group consist of repeated alternations of dark-grey shales, with thin beds of greywacke, beds of ashy grit, and occasionally beds of well-marked tuff. The whole character of these rocks evidently points to a series of submarine accumulations having taken place at no great distance from a volcanic area, from which every now and then, during explosions more violent than usual, quantities of ejected material were cast forth with sufficient violence to find their way out to sea, miles beyond the centres of eruption. Between each of these paroxysms quiet deposition of ordinary silt and mud went on as usual. There is known to be a considerable thickness of rock of this alternate volcanic and sedimentary type here; but sections around Knock Pike cannot be continuously traced for any great distance. Rocks of this nature occur on the low hill locally known as Flegda (Flagdaw on the Ordnance maps), but they are much better exposed in the contiguous area on the north-west.

UPPER SILURIAN.

GRAPTOLITIC MUDSTONES.

The exposures of this thin but geologically-important horizon in the present locality have long been known to collectors of fossils; as well as to geologists in general; and have been visited to at least the same extent as the typical areas in the Lake District and Moffat. The exposures occur in two localities. One of these is in Knock Gill, rather less than a hundred yards below, or south of, the junction of this with the small stream flowing from the pastures on the north-east, and called Small Burn on the six-inch map. The exposure referred to is unsatisfactory: possibly it may be partly cut out by a small fault, as only a very little thickness could be seen when the zone where it should come was purposely laid bare during the progress of the Survey. The other, and more-easily-examined exposures, are in the course of Great Rundale Beck, between two and three hundred yards above its junction with Knock Gill. They are seen partly in the bed of the stream, partly (and much better) in the wooded bank that bounds the stream on the south. There is some boulder clay above both of these places, so that one cannot always be sure of

finding them alike on different occasions. It is from the Rundale Beck section that most of the graptolites have hitherto been obtained here.

In lithological characters the Graptolitic Mudstones consist of dark sooty brown, almost black, mudstones, which are generally massive here, instead of being shaly as they are at some localities. Their texture upon a broken surface reminds one somewhat of an indurated fuller's earth. Very frequently the divisional planes traversing this rock are glazed with films of limonite, which not uncommonly give rise to iridescence. Anything like lamination is to be found only in its uppermost zones where it graduates by interlamination into the overlying Pale Slates. No reliable estimate of its thickness here can be given, as its base is not clearly exhibited anywhere in this area. It appears to be thinner here than usual, and may not much exceed about twenty feet.

The following list of fossils from the Graptolitic Mudstones of Great Rundale Beck is taken from the paper by Messrs. Marr and Nicholson :—*

- Monograptus leptotheca, *Lapw.*
- „ cyphus, *Lapw.*
- „ tenuis, *Portlock.*
- „ triangulatus, *Harkness.*
- Rastrites peregrinus, *Barr.*
- Petalograptus ovatus, *Barr.*
- Diplograptus sinuatus, *Nich.*
- „ Hughesii, *Nich.*
- Climacograptus normalis, *Lapw.*

For the reason given above it is difficult or next to impossible in this area to arrive at any definite conclusion regarding the physical relation of the Graptolitic Mudstones to the underlying Coniston Limestone Series.

STOCKDALE SHALES OR PALE SLATES (TARANNON SHALES).

The lower beds of the Coniston Flags graduate downward, through the introduction of light grey bands, into the underlying Pale Slates. The passage is so gradual in some cases that only the discovery of the graptolites characteristic respectively of the upper, or of the lower, strata will enable us to draw a satisfactory boundary-line. In Knock Gill the actual junction-zone is not clearly exposed, but it must cross Knock Gill between sixty and seventy yards below the point where Great Rundale Beck joins that stream. A little below this point some part of the passage-beds is seen. The Pale Slates present a peculiar facies over a large area in the north-west of England as well as in Wales. This is somewhat difficult to describe, but, once seen, is not easily forgotten. They consist of rather thickly-bedded rocks, of a pale lead colour, often with a tinge of green, so as to be of that peculiar green biologists term glaucous. They are generally traversed by close clean-cut joints, and are not often affected much by cleavage.

* Quart. Journ. Geol. Soc., vol. xliv. (1888) p. 699.

A few bands of a more shaly nature occur at irregular vertical intervals. In hand-specimens the rock is so fine-grained and porcellaneous in texture that at first sight it reminds us of one of the hálleffintas, or, perhaps, even more, of some of the beds of very fine volcanic mud which occur, near Ambleside for example, interstratified with the higher members of the Borrowdale Series proper. In some respects its close texture, its uniformity in both lithological character and in thickness over large areas, its generally-unfossiliferous character, its almost invariable association with more or less manganese-oxide, and its liability (where stained) to pass into mudstones of a red colour—all tend to remind one of some of the deep-sea oozes. Its association with graptolite-bearing mudstones, both above and below, strengthens this impression. The grey bands are nearly or quite unfossiliferous; but some of the dark bands which mark the passage upwards into the Coniston Flags, yield fossils, which are chiefly graptolites; and, similarly, the thin dark bands which occur interlaminated with the grey near the base also contain graptolites. The assemblage of species in each case is confined to, and therefore characteristic of, its own respective horizon.

The best exposures of the Pale Slates in this area are to be seen around the junction of Great Rundale Beck and Knock Gill. The upper beds are seen here in some small cuttings by the side of the footpath leading from Knock to the back of Dufton Pike. Other exposures occur in the bed of the stream itself. At one of these the Pale Slates are traversed by an interesting example of a minette dyke, which will be noticed in more detail further on. These rocks can be studied in the course of Knock Gill and on its banks for a further distance of about one hundred and fifty yards, at which point beds older in the series rise to the surface. Near the base, as already mentioned, dark graptolite-bearing laminæ begin to alternate with rock of the grey type. From one of the higher of these dark bands in Knock Gill, Messrs. Marr and Nicholson* record:—

Monograptus turriculatus, Barr.

„ *lobiferus*, M^cCoy.

Rastrites distans, Lapw.

From another dark band slightly lower in the series at the same locality the same authors (*loc. cit.*) record:—

Monograptus broughtonensis, Nich.

„ *pandus*, Lapw.

Cyrtograptus grayæ, Lapw.

„ *spiralis*, Geinitz.

Retiolites geinitzianus, Barr.

„ [form like] *macilentus*, Törnq.

Other exposures in this locality are to be found in a small quarry on the north side of great Rundale Beck, near its junction with Knock Gill. A little farther up the same stream and on the south bank, occurs another exposure of beds near the base, in which imperfectly-preserved graptolites referable to those just

* Quart. Journ. Geol. Soc., vol. xlv. p. 699.

mentioned again occur. Similar beds cross the stream again at a point due north of the summit of the small hill called Cosca.

Only an approximate estimate of the thickness of the Pale Slates here is possible. The total thickness may be about two hundred feet.

CONISTON FLAGS.

Rocks undoubtedly belonging to this part of the Upper Silurian occur between Knock Pike and the Outer Pennine Fault. They are best seen in Knock Gill, immediately to the north of the line where the Fault crosses that stream, and they are also exposed on the north-west bank for a short distance on the up-cast side of the Fault. One of the best exposures is on the slopes of a wooded bank in the third inclosure on the left going up the Gill from the ford leading from Knock to Far Close. Here the Coniston Flags present their typical aspect, which is that of thickly-bedded, dark grey, fine-grained argillites, which are characterised by a striping due to rapid alternations of thin laminae of slightly different colours and textures. As is usual in this part of the kingdom, these rocks are affected by cleavage, which crosses the bedding at high angles, and which causes these rocks to split more readily across, than along, the planes of deposition. Consequently any fossils that may occur in them are difficult to find in good condition. Graptolites, however, may be obtained in a fair state of preservation. One of the commonest occurring here is a monoprionidian form strongly resembling *Monograptus priodon*, which, however, Messrs. Marr and Nicholson refer to *M. vomerinus*, Nich.*

The strata hereabouts are affected by several folds whose axes range in an east-north-easterly direction. The Outer Pennine Fault here has a direction nearly north-westerly; so that there seems to be no connexion between the direction of the great fault and the present lie of these rocks.

On the whole the net result of the dips is to bring lower beds to the surface as the rocks are followed towards the north-west, so that the base of the Coniston Flags rises to the surface within a short distance in that direction. In a south-easterly direction it is not clear whether these rocks are cut off by a fault, or whether the base may not rise to the surface again, a short distance to the south-east of Far Close; but the drift-covered nature of the ground leaves us uncertain upon this point.

IGNEOUS ROCKS.

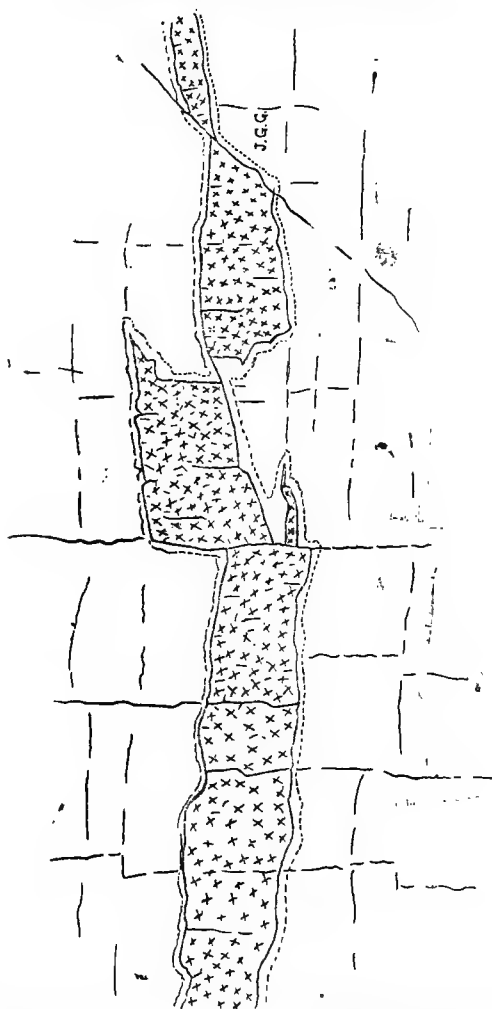
These, though few in number, and limited in extent, are of more than general interest in several respects.

Minette Dyke.—Three, or perhaps four, dykes of Minette occur close to Knock. A small, and easily-overlooked dyke of this rock occurs in the Coniston Flags of Knock Gill rather more than a hundred yards below where the base of these rocks rises to the surface. Another dyke (the one figured as Minette from Swindale Beck, Knock, in Teall's "British Petrography, Pl. xxxii.

* Brit. Graptolites, pp. 52-3, fig. 21.

Fig. 2") is well seen near the footpath at the west end of Great Rundale Beck. The same dyke—having a trend almost exactly in the direction of the summit of Knock Pike—cuts Knock Gill, and is very well seen both in the banks of the stream and in its bed. Here its relation to the enclosing Pale Slates can be easily studied. It gives rise to various local expansions and ramifications, some of which have eaten their way into the strata along the joints and other divisional planes. The following sketch-plan may serve the purpose of giving a general idea of its behaviour :—

FIG 1.—*Plan of Minette Dyke seen in the Pale Slates of Swindale Beck or Knock Gill.*



The dotted outer line represents the altered zones of the Pale Slates.
Length of plan 10 feet.

The same dyke may easily be traced in the west bank of the Gill for about one hundred yards to the north; beyond which all further traces of it are lost.

Another minette dyke, with the same N.N.W. trend, occurs on the eastern slopes of Knock Pike, and may be traced northward from the Gill for more than a hundred yards. Another exposure of a similiar nature occurs a short distance to the west of the point where the last-mentioned dyke terminates. These dykes are typical in petrographical character, and therefore call for no further remark here. All of these contain more or less free quartz in the form of blunted dihexagonal pyramids.

Microgranite.—One of the best known rocks from the Pennine Silurian area is the so-called Dufton Granite. This occurs as an elongated mass, spindle-shaped in plan, intrusive in the Coniston Limestone Series, and exposed rather more than half a mile to the east of the village of Knock. It is well seen in the occupation road about two hundred yards to the south of the Hallsteads farmhouse, close to one of the outbuildings; and again in an old quarry about the same distance to the west of this. A second exposure of a closely-related rock occurs on the east side of the same occupation road, about a hundred yards to the south of the first-named locality. The Dufton rock was examined and reported upon by Dr. F. H. Hatch for the Geological Survey, some years ago. In general terms it may be described as a fine-grained microgranite, which differs from the normal type of these rocks in containing large rhombic crystals of muscovite. Mr. Watts has lately re-examined the rock, and now describes it.

The second exposure referred to presents a somewhat different aspect, and consists of a microgranitic aggregate of light-coloured felspar without the conspicuous development of doubly terminated quartz crystals, and without the muscovite; but containing instead acicular crystals of biotite.*

J. G. G.

The Dufton Microgranite.—This rock is pink in colour, with the appearance of a fine-grained microgranite in which crystals of quartz and felspar are embedded. In some specimens large hexagonal tables of muscovite half an inch across occur, while smaller flakes of biotite are usually present, becoming of greater importance at a few localities. Microscopically the matrix is microcrystalline, consisting of flakes of mica set amongst a granular aggregate of quartz and felspar. The porphyritic plagioclase felspars show albite and pericline twinning, and are generally very sharply idiomorphic, while those of orthoclase felspar are more irregular in shape. The white mica is more or less pseudomorphed by a turbid brownish product and the biotite is not strongly pleochroic but is undergoing change into chlorite. The quartz is crystalline and more or less rounded, with inliers of the ground-mass of the rock. A little apatite is present. This description applies also to a rock collected from Roman Fell.

W. W. W.

* See Harker, Quart. Journ. Geol. Soc., vol. xlvii. p. 520.

CHAPTER V.

CARBONIFEROUS.

Area south-east of the River Eamont.

We will now describe the Carboniferous Rocks according to the scheme set forth in the Introduction, beginning with the lowest beds, or those which are sometimes referred to the Upper Old Red Sandstone.

"UPPER OLD RED SANDSTONE" OR BASEMENT BEDS OF THE CARBONIFEROUS.

The lowest beds consist of a very variable thickness of dull red conglomerate, with some irregular and quite subordinate beds of red sandstone and marl. The constituents are chiefly fragments of greywacke and various argillaceous rocks, together with some stones of eruptive origin. Many of these may have had a local source. Others, however, appear to be foreign to the district, many of them resembling some of the older rocks found in the south of Scotland. Possibly the materials of much of the conglomerate under notice may have been derived from an older, but post-Silurian, conglomerate, now entirely removed from this area. With these occur some fragments of limestone, also unlike any now found in the districts. There are also some few quartz pebbles. Many of the stones are but slightly rounded—the proportion of angular and sub-angular stones to well-rounded pebbles being about as two to one. The constituents lie for the most part with their longer axes parallel to the planes of bedding. Their size is variable; but stones exceeding a foot in diameter are not generally common. The conglomerate is compacted by a loamy matrix, which is usually more or less of a dull indian-red tint. Ferruginous films of the same colour give rise to a glaze upon many of the stones.

Rocks of this type—varying much in thickness on account of the minor inequalities of the rock-surface upon which they are deposited—appear to lie at the base of the Carboniferous rocks from the southern margin of the map to Ullswater. They are well seen in the North-Western Railway-cutting at Shap Summit; at Thornship; on the banks of the Lowther at Shap Abbey; in Rosgill Hall Wood; at the confluence of Setterah Sike and Heltondale Beck; and around Rowhead near the foot of Ullswater.

LOWER LIMESTONE SHALES.

In the country lying to the south-east of the area embraced by this map the Basement Conglomerate is overlaid by, and graduates upward into, a series of conglomerates, containing a much larger per-centage of quartz pebbles, and few or no stones which are clearly foreign to the district. These conglomerates are

interstratified with greenish and reddish sandstones, which are occasionally calcareous, with coloured shales—grey, greenish, and chocolate-coloured, and with impure, and often pebbly, limestones. Strata similar to these, in both geological position and lithological character, have elsewhere usually been referred to the Lower Limestone Shales.

Beds of this type are seen at Shap Summit Cutting; but they appear to die out as the rocks trend towards the north-west, as in that direction the Upper Old Red or Basement Conglomerates are directly succeeded by the rocks to be next described.

CARBONIFEROUS LIMESTONE AND YORED ALE SERIES.

Above the horizons last described the Lower Carboniferous rocks, including under this title the Carboniferous or Mountain Limestone and the Yoredale rocks, consist, in this area, very largely of beds of marine limestone. In dealing with these the most convenient plan of treatment will be to describe under the heading of each of the minor subdivisions, first, its broader lithological features, and the nature of the changes it is known to undergo as it is traced from one point to another; and, secondly, the chief localities where it is best exhibited, beginning with the lowest stratum, and taking the localities in geographical order from the south-east north-westward.

The Limestone of Shap.—This may be described as a series of thinly-bedded, impure, limestones, often more or less arenaceous, and locally containing grains or even small pebbles of milky quartz. In many places it is more or less dolomitic, apparently through the introduction of magnesian carbonate at some period subsequent to its deposition. In consequence of this alteration the limestone commonly encloses drusy cavities, which are usually lined with crystals of calcite and pearl spar. Calcareous shales part the limestone at irregular vertical intervals.

The individual beds of limestone become more sandy, and thin away one after the other, as they are followed towards the north-west. They may be said to have disappeared almost entirely at the foot of Ullswater.

Strata of the above-described type are to be seen at the following localities, taken from the south north-westward:—Busk; Shap Summit Cutting; in several quarries by the Kendal roadside, between the last-named locality and Shap village; Shap Thorn; Jingling Pot; above the Railway Viaduct at Force Bridge; several quarries in and around Shap village; in the elbow of the Lowther above Shap Abbey; Rosgill Hall Wood, and thence nearly continuously to Bampton Grange; above and below High Knipe; on the right bank of the Lowther $\frac{1}{2}$ mile S.S.W. of Whale. Thence, gradually becoming more arenaceous, and at the same time thinning, as they are traced north-westward, impure representatives of the Shap Limestones may be seen here and there on the moors nearly up to the foot of Ullswater, beyond which they are no longer traceable.

The Ash Fell Beds.—This subdivision of the Mountain Limestone may be described in general terms as a series of sandstones and thin shales alternating with subordinate beds of more or less impure limestones. As the sandstones are traced towards the south-east they become increasingly calcareous, and eventually pass, in that direction, through the condition of arenaceous limestones, into the ordinary type of this rock. The limestones, followed towards the north-west, become less and less pure, and at the same time thinner, until, near the northern edge of the map, some of them disappear altogether.

In colour many of the sandstones vary considerably. At one locality this may be of the ordinary pale yellow or buff, while at another, perhaps at only a short distance, the same stratum may present various shades of dull red, purple, or pink. There can be but little doubt that this latter feature is due to infiltration of colouring matter from some overlying stratum since removed by denudation. In all probability this colouring matter was derived from some part of the Permo-Triassic series. To the same source may be attributed the dolomitization of the limestones associated with these Ash Fell Beds.

Rocks belonging to this subdivision are exposed at the following localities:—Several quarries in sandstone on Crosby Ravensworth Fell; near Shap Thorn and Jingling Pot; in various quarries to the east of Shap; from this latter, in numerous quarries and natural exposures, as far as High Knipe; and again on the moors to the south of Askham. From this point north-westward the gradual diminution in thickness of the underlying Shap Limestone results in these Ash Fell Beds becoming the lowest members of the Mountain Limestone, which position they occupy in the north-western part of the area under notice.

The Limestone of Knipe Scar.—The Ash Fell Beds are succeeded by a considerable mass of limestone, which, like the calcareous rocks that lie beneath it, is thickest and most pure towards the south-eastern limit of its extent, and becomes gradually thinner, and less pure, in its lower beds, as its course is followed in the opposite direction. Like the beds beneath it, this subdivision may be compared to a series of thin wedges with their thick edges directed towards the south-east, and which come to an end one after another, beginning with the lowest, as they are traced for a few miles towards the north-west. The average rate of attenuation is exceptionally high for the Carboniferous Limestone of this part; but it rarely exceeds, and generally falls short of, fifty feet in a mile.

Limestones on this horizon form the remarkable surface—consisting, over a large area, of perfectly-bare grey rock—which extends from Asby Moor, past Crosby Ravensworth Moor, Hardendale, Shap Common, Knipe Scar, the lower scars of Lowther Park, part of the moors south of Askham, past Sockbridge to Stainton. Northward of this point the gradually-diminishing thickness of the beds, the presence of numerous

faults, and the increasing mantle of drift, combine to lessen the importance of this subdivision.

The beds immediately succeeding the subdivision just noticed are much more persistent in regard to both their thickness and their lithological character than are the beds below. This remark applies, not only to the limestones, but also to some thin sandstones and shales which are interstratified with them. Even in the case of these, however, the general rule applicable to the lower subdivision of the Mountain Limestone in this area—that there is a progressive diminution in the thickness and purity of the limestones as they are traced from the S.E. towards the N.W., and a corresponding progressive augmentation in the proportion of materials of terrigenous origin—holds equally good. In the present case the changes are much more gradual in character. An inspection of the map should suffice to inform the geological inquirer of the trend of these minor subdivisions, which, except on account of their persistence, and therefore of their usefulness in tracing horizons, are of no special value in the present connexion.

The Limestone of Maulds Meaburn.—The limestones just referred to are succeeded by shales, which graduate upward into a series of flags and sandstones, and which, although variable in detail, are nevertheless fairly constant as a whole over very extensive areas. These beds are succeeded by the Limestone of Maulds Meaburn, which is probably identical with the Hardra Limestone of the areas to the south-east, and the Jew Limestone of the upland area to the north of the district under description. The Limestone of Maulds Meaburn is usually a compact, close-grained grey limestone moderately thickly bedded. Like most of the other limestones of this lowland area it is locally altered into dolomite, and is in places much impregnated with ferric oxide, probably derived from the same source as the carbonate of magnesia. The limestone itself possesses hardly any noteworthy lithological characteristic; but where good sections of the beds above and below are to be seen this limestone may be observed to lie on sandstone which is rarely or never markedly calcareous, while the overlying strata are sandstones with generally only a very small thickness of intervening shale. These characteristics of the Hardra Limestone and its immediate associates are constant from North Yorkshire to the borders of Northumberland.

Before describing the localities at which this rock may be seen it is proper to remark here that this limestone, and the others which succeed it above, retain their thickness and their field-characteristics in general over several hundreds of square miles. They are usually based upon sandstones, and are almost invariably succeeded above by more or less shale, which is generally calcareous near its junction with the underlying limestone, and becomes more arenaceous as it is traced upwards into the overlying sandstone. These sandstones and shales maintain their general lithological characters, but increase in thickness, as they are followed

northwards and eastwards; but while the limestones retain their thickness and their purity as they trend towards the north-west, the intervening sandstones first, and then the shales, tend to become progressively thinner, until eventually the limestones coalesce into one nearly-undivided mass. The reader who thoroughly comprehends these facts and their bearing need to be told very little else regarding the limestones of the area under notice, as the above statements will serve to explain all the anomalies in any way connected with the original structure of these rocks.

The Limestone of Maulds Meaburn is well seen between Bell Foot and Flass House, near Crosby Ravensworth; at Maulds Meaburn Green, Harberwain Riggs, and Wickerslack Moor; in the beck descending from Wickerslack Moor to Reagill Grange; near Wyebourne and Wyegill Plantation; from Threaplands to Towcet; below Windrigg Hill; in the left bank of the Leith above Thrimby Bridge. Thence for some distance its course is obscured by drift, and its identification becomes doubtful.

The sandstones and shales overlying the Limestone of Maulds Meaburn locally contain a very thin seam of coal, and also here, as generally elsewhere, at least two bands of impure limestone which are too thin to make much show at the surface, and which are in consequence, but rarely seen. Strata belonging to this subdivision are exposed at Morland Bank, Low Wood Beck, Wickerslack, the gill north of Wyegill Plantation, on the road below Greenrigg Quarry, Threaplands, Longlands, Towcet, between Little Strickland, High Hall, and Thrimby Bridge, the bank of the Leith at Sheriffs Park Wood, and in the bed of the river to the north. In consequence of the numerous disturbances of the strata in the district to the north-west of these localities, and also of the rarity of good sections, the exact correlation of the rock seen in some of the exposures is often open to doubt.

The Limestone of Little Strickland.—This limestone, which is regarded as the equivalent of the Simonstone Limestone of the typical Yoredale area, and of the Tynebottom Limestone of the upland areas to the north, consists, like the limestone below, of close-grained, thickly-bedded, grey limestone, generally free from earthy admixture, and often locally altered into dolomite, or even partly replaced by ferric oxide. This general description will suffice for the rock everywhere within the limits of this map. It is seen in the bed of the Lyvennet at Low Bridge; on the north bank of Low Wood Beck from Byesteads to Reagill Grange; at Greenrigg Quarry, and thence to Threaplands, in the neighbourhood of which are several exposures. It is well seen at several places near Little Strickland, the principal quarries being near Longlands and north of Towcet Cottages. From below Moorrigg it extends in almost unbroken succession to Lowther Deer Park, and again in the banks of the Lowther near Yanwath Hall.

The Limestone of Little Strickland is overlain by shales, which are followed by alternations of sandstones and shales accompanied

by a thin and not often very pure, but remarkably persistent, bed of coal. Associated with this series of beds there generally occur two beds of limestone, which are usually not of sufficient thickness to be traced on the ground for any great distance, but which are, nevertheless, persistent over several hundreds of square miles, from the dales of north-west Yorkshire far away into Northumberland, where these limestones are respectively known as the Post Limestone and the Cockleshell Limestone.

Amongst the localities where beds referred to this subdivision are to be seen may be mentioned the following:—Scattergate Quarry and the adjoining gill; Maulds Meaburn Green; Barnskew Bank. The coal-seam above referred to may be traced for three miles or more in the neighbourhood of Reagill. It is rarely more than 8 or 10 inches in thickness; but at one time, judging by the number and extent of workings in it, it must have been regarded locally as of considerable importance. Workings on this horizon can be traced from the pastures east of Crosby Ravensworth to Little Strickland or even farther—though it by no means follows from this that the seam is actually continuous the whole way. The sandstone associated with the coal seam is seen at intervals from the localities mentioned above, past Lowther Park to Tirril.

The Limestone of Reagill.—In the Lyvennet at Barnskew fine-grained, hard, dark-coloured limestone dipping N.E. at 7° is traceable to below Whitehouse. This limestone overlies the coal just referred to. It should be mentioned here that there is some doubt regarding both the exact position in the series of the limestone in question, and also of its correlation with limestones exposed in the areas both to the east and the west of the Lyvennet. This is owing to several causes. One is the uniformity in character of the limestones near this horizon, so that it is very difficult and in many cases impossible for the field-surveyor to decide which he has before him; another is the fact that the sandstones and shales which separate the limestones are steadily thinning as they are traced towards the north-west, so that a limestone above or below one which is being followed across the country may appear to be continuous with it. The last, and most important, reason, is the absence of exposures continuous along the outcrop for more than a short distance. Considerable uncertainty, therefore, attaches to the identification of this limestone and the one that succeeds it.

The sandstones and shales that succeed the limestones just noticed are seen here and there in a few quarries and natural exposures; amongst which may be mentioned Meaburn Park; White Stone, Newby; Newby Pasture; the Leith, near Strickland Mill; Hackthorpe and Lowther.

The Limestone of Maulds Meaburn Edge.—This forms a bold escarpment in Meaburn Park, where it has been quarried for lime. It is seen in a well near Lankaber, and in large quarries west of Barnskew. Limestones which (with some doubt) have

been referred to this same horizon occur in Newby Pasture; and Limelands Quarry south of Great Strickland (where the limestone in question contains siliceous bands like those which are generally characteristic of one of the higher limestones of this series). The limestone of Limelands Quarry occurs again in the bed of the Leith directly below Hackthorpe, and in Lowther Park, where this limestone is thick and is well exposed. From near Woodhouse ($\frac{3}{4}$ m. W.S.W. of Clifton) there are several exposures as far as the railway $\frac{1}{2}$ m. S.E. of Yanwath.

East of Lankaber very irregularly current-bedded sandstone is seen not far above the limestone; and at 300 yards N.E. of High Lankaber, coarse rubbly sandstone similar in lithological character to that seen near Hoff, is exposed. The same rock is seen at Little Beck, Kings Meaburn Mill; Low Moor; Hard Ing; near Weather Crook, Thorny Croft, and to the S.W. of Great Strickland. At all these localities the sandstone is generally coarse, almost like typical Millstone Grit, and like this, it contains much detrital muscovite and decomposed felspar. Very commonly, like many other of the sandstones of this part, it is locally and irregularly stained of a deep red, brown, and dull purple. Green discoloration spots, characteristic of red strata whose coloration is an original feature, are, however, conspicuous by their absence.

It may be remarked here that a coarse grit of this same general nature, occurring in association with an encrinital limestone charged with much siliceous matter in the form of bands and chert nodules, is a characteristic feature of the part of the Yoredale Rocks below the Main—Twelve Fathom—Great—or, as it is termed on the map, the Great Strickland Limestone, presently to be described. This association, which is peculiar to this zone, has been of considerable value in tracing the rocks in question across areas confused by faults and obscured by drift, such as form so much of the lowlands of the country under description. In the Alston district a grit of similar character, but of lesser thickness, is so constant in its occurrence above the Four Fathom, or Lower Undersett Limestone, as to have received a distinctive name—the “Quarry Hazel.” In the same district the Upper Undersett of the Yorkshire dales occurs as a thin but very constant band of limestone lying between the Quarry Hazel and the Great Strickland Limestone. A similar limestone, too thin to be separately mapped, is occasionally seen in this district above the coarse grit just noticed.

Above the horizon of the limestone last referred to occurs a thin series of flags sandstones and shales which underlie the base of the Limestone of Great Strickland. These do not present any features specially calling for notice; we therefore pass on to the description of this, which is the chief limestone of the Yoredale Rocks here as elsewhere in the neighbourhood.

The Limestone of Great Strickland (The Main—Great—or Twelve Fathom Limestone).—This, nearly everywhere in the north-west of England, consists of a close-grained, grey limestone,

generally in moderately-thick beds (or posts as they are called here), more or less encrinitid in composition, and tending, locally, to be somewhat siliceous in its upper parts. It varies in thickness from seventy feet at the eastern end of this district to about thirty-five or forty feet, which may be taken as its average thickness here.

Here it is often much dolomitized along joints and other divisional planes, and drusy cavities are, consequently, of common occurrence. In some places the alteration has proceeded further and the dolomitic parts graduate into ferruginous dolomite and from that into hæmatite. This general description will apply to it over the whole of the lowland district.

It is seen, and largely quarried, at many localities; amongst which may be mentioned the following:—

Barwise (or Barras) Hall; several places near Kings Meaburn, where it forms Jackdaw Scar; Byesteads, and several other places near Morland; from the east end of Newby to Dallen Bank it is nearly continuous; at Great Strickland, as the name employed here implies, it is well seen; on the right bank of the Leith at Old Scar; Bowbert-hill Quarry shows at least thirty feet of this rock.

The uppermost beds are seen in the Lowther near Clifton, where they consist of impure limestone stained red by infiltrated iron from the Red Rocks which until lately covered them.

Sandstones and shales succeed the Great Strickland Limestone. These are seen at Woodhead; between Mealy Sike and Greengill Sike; Lancaster Bank Wood; Woodhouse Gill; and in the Leith above Melkinthorpe. They are seen again at Clifton; and are especially well shown at Hughs Crag Quarry between Clifton and Penrith.

J. G. G.

(Partly from notes by W. H. D.)

Area east of the River Lyvennet.

CARBONIFEROUS LIMESTONE SERIES.

The rocks east of the River Lyvennet, now remain to be described.*

The lowest of the Carboniferous beds described by Messrs. Dalton and Goodchild do not come into the present area. Under the names of Basement Beds, Ravenstonedale Limestones, Ash Fell Beds, and Melmerby Scar Limestone (part of which lies in the area), they have been described in the Memoirs on the Quarter-sheets 98 N.E. and 97 N.W., dealing with tracts to the south and south-east.

The whole series consists of a great thickness of limestones shales and sandstones, whereof the limestones predominate in the lower and the sandstones in the upper beds.

* Contained in the Six-inch maps of Westmorland, Sheets 9, 15, and 22.

The rocks have a gentle inclination of which the general direction is north in the ground directly south of Appleby, but puckered by gentle corrugations, which give dips ranging from N.W. to N.E.

The southern portion, consisting chiefly of large areas of thick limestones, is more bare of Drift than the lower ground to the north which is made up of more rapid alternations of rocks, and before reaching the main body of the Permian Rocks is almost covered everywhere by Glacial drift.

This may be probably accounted for by the former being higher ground, and partly because great tracts of limestone give less facility for the manufacture of stiff Till than do the rapid alternations which contain shales and sandstones, as well as limestones. A Till which is made up of limestone-fragments is almost a gravel, and more easily dissolved or washed away than one into the composition of which clay largely enters.

The Limestone of Knipe Scar.—The main mass of limestone above the Ash Fell Beds called Knipe Scar Limestone—or L. in the Table of Rocks (p. 4)—forms a large tract in the S.E. corner of the area over a wild tableland, having from 900 to 1,200 feet of elevation, intersected by the small valleys. The beds are undulating in gentle folds, whose axes lie about N. 30° E. and S. 30° W., the synclinals forming ridges, and the anticlinals hollows, as is so often the case elsewhere. One of the former constitutes the crest of Muddy Gill two miles south of Asby. A thin bed of shale skirts the north-west side of this crest and runs round to its southern flank making a little scarp all the way. This shale appears with increased thickness to run along the valley by Grange Hall and Asby Grange and mounts all the ridges in succession to Crosby Garrett, and is shifted at least once by a N.N.E. fault, but west of the points where we took it up it has not been recognised. These limestones are very cherty in places and occasionally the surface seems to be made up of fragments of chert and yellowish soil which is probably the insoluble residue of the limestone, a result of weathering.

The Limestone (L.) contains, a little south of Asby in the beck-bottom, a fine "Giants Cauldron" or Kettle, ground out of the rock by an eddy in flood-time. It is eight or ten feet deep with smooth grey sides of vase-like form swelling towards the middle and contracted at top and bottom. It is usually full of limpid water through which may be seen, at the bottom, the pebbles whose action in flood-time have excavated it.

The next noteworthy bed is a thin sandstone usually of rather fine grain and containing in places a little lenticular bed of limestone in the middle of it. It has a very persistent range, and has been traced from Crosby Garrett on the S.E. to Stainton on the Eamont, a distance of nearly twenty miles. It enters the area on the east near Grange Hall, above Asby, and runs along the right flank of the valley above that house. Here it is a

purple and red coarse grit. It descends to the level of the beck at the fault marked on the map and probably ascends the corresponding slope on the other side. Its course is concealed by drift for a short distance, but around High Burn on the west it takes a tortuous course, the result of minor foldings of the rocks, and two little inliers of the underlying limestone rise through it. It runs alongside the road from Asby to Crosby Ravensworth for a short distance, an old sandpit now filled up having been formerly worked in it. The fault against which the sandstone abuts here, and by which it is cut off on the north, runs a little south of Asby Great Kettle in Asby Beck and along the valley called Sayle Bottom, though its exact limits are not easily definable. It probably runs in the direction of Friar Biggins* to which place an anticlinal fold runs continuously, though no actual break is discernible.

The workings of an old copper mine are to be seen along this line, on the road from Asby to Orton, but no information could be obtained about it.

The sandstones are repeated by the fault mentioned, so that they cross Asby Beck again further north, probably about the middle of the village. Though not seen here the absence of limestone renders their presence probable, and the beds are fairly seen some way above the right bank east of Asby Kettle and Town Head. They are concealed by drift for some distance, but their presence may be inferred above Whitewall where the over and underlying limestones are well seen, the latter with a row of deep pot-holes. The sandstones put in an appearance as the drift clears off by the road east of the tumulus; and again, beyond the township boundary marked on the map on Gathorn Plain, a little lenticular mass of limestone with a bed beneath it bearing a strong resemblance to a fire-clay may be seen in the little escarpment. Very fine sandstones occur here.

The beds have a north-westerly range from this point, though the dip is north at 6° to 8° , by reason of the form of the ground. They may be traced hence to Crosby Ravensworth, more by the form of the ground and the overlying limestone than by exposure of the rock itself, though the beds are seen at least once between the Orton Road and that village. A small inlier of these beds may be seen in the little gills about Gathorn Ashes, S.W. of the Hall, which have cut down through the overlying limestone at the head of Scale Beck. The most westerly branch gives in descending order, limestone, shale, limestone, sandstone. A spring comes out at the junction of the last two.

The Limestone of Askham.—The limestone next above the beds just described (K. Limestone of Askham) is usually a dark grey or black limestone. It makes a considerable spread on Gathorn Plain, where a dip-slope tolerably bare is to be seen, and it runs down to beyond Gathorn Hall in Scale Beck. Two little inliers of it may be seen in the gill west of Halligill farm-house. The dip is

* In Quarter-sheet 98 N.E.

northerly from 8° to 5° . Beyond this point it suffers temporary eclipse from a great moraine mound called Rakes, but reappears again north of Whitewall where several deep pots occur in it. It may be traced by pots about half a mile, the overlying sandstone being seen on the north side of Dale Beck close to Asby, which village it crosses, and ascends the right bank of Asby Gill, rising opposite to Town Head to the "Great Kettle" fault. This brings it down to the beck again, and it is the limestone in which Asby "Pate-Hole"* is excavated, spreading with a dip-slope where not concealed by drift over the ground about High Barn and Whitestones where Clockeld and Stenkeld both call attention to springs from it. At the next fault it is brought against a limestone higher in the series, from under which it rises from the bottom of the valley, its base rising above Grange Hall and by Crosby House where it enters the area of the adjoining map.

The beds above the Gathorn Plain (or Askham) Limestone do not anywhere present a good continuous section. At Coalpit Hill, where the Orton Road diverges to Gathorn Hall and Asby, tile-works used to be in operation, and the excavations showed black shale with overlying Boulder clay. The occurrence of the black shale seems to have been considered sufficient justification for a trial for coal, whence the name. After this had been in progress for some time the advice of E. W. Binney was, I believe, asked and the work was wisely stopped. These beds seem to present a predominance of shale in the lower part and sandstone in the upper. Sandstone is to be seen in the road a little above the locality mentioned beneath the next higher limestone and along the same line a little further west the following beds were noted:—

Limestone, 9 ft.

Shale, 5 ft.

Sandstone, 3 ft., and probably more.

These beds may be seen in several places between the limestones when following the scarps down to Crosby Ravensworth. In the other direction they are soon lost beneath the drift and weathered slopes of Scale Beck.

The Limestones of Maulds Meaburn and Little Strickland.—I. and J., the next two limestones in our section, may be best taken together. They form an outlier on the conical hill called Mark's Close south of Gathorn Hall, where they may be well seen, and the boundaries in many places fairly traced. The upper forms a capping to the hill with a dip-slope north, and the lower runs round the west side and extends further to the N.E. surrounding an adjoining hill. A thick series of sandstones lies between and has been quarried here and there on both hills, but shale intervenes above the lower limestone.

A section at Hallgill gives limestone on calliard, on freestone, and may represent the upper limestone faulted down. A thin limestone about half-way between this and Stangerstones probably represents the lower. It rests on sandy shales which are more clayey below.

* Spelt "Pale-Hole" on the six-inch map. Pate is a local name for a badger.

At Stangerstones we see the following succession :—

Limestone,	10 ft.
Sandstone,	6 ft.
Limestone,	7 ft.
Sandstone,	7 ft.

The Limestone at the top of this section is probably much thicker and spreads north by Twins Cottages to Scale Beck. These two limestones in this section most likely represent the upper one of Mark's Close, but the beds about here are exceedingly difficult to trace with certainty.

If we turn to the main mass of these two limestones we find them running with fair regularity from near Maulds Meaburn to High Field, north of the Scale Beck Valley. The upper one passes under Flass House on the Lyvennet, and they both slowly rise along the bank east of Crosby Ravensworth, and are visible through a great part of their course. The upper bed covers by far the greater area.

They are both cut by a north-easterly fault above the so-called "British Settlement" of Howareles, with a downthrow on the N.W., small but slightly increasing towards the N.E. in amount.

A small fault with a similar direction but with a downthrow on the opposite side, may be seen at about a thousand yards further on, not far from the junction of the Asby and Crosby bridle road with the main road to Orton. This also cuts both limestones.

Above Gathorn Hall the lower band is lost in the Glacial drift, but reappears again south of Highfield, where a soft yellow sandstone occurs between them. The upper bed is seen again at Scale Beck Quarry with sandstones below, and in the stream beneath, a thin limestone rests on clayey shale, and higher up stream, but dipping beneath these, is a red ferruginous limestone.

The upper of the two limestones we have been tracing was considered by Mr. Goodchild to be the equivalent of the Hardra Scar Limestone, which has been taken in many places as the top of the main mass of the Mountain Limestone.

The beds intervening between this and the next limestone above (of noteworthy dimensions), appear in Bastern Gill S.E. of Flass House as massive sandstones, but through the greater part of their course they exhibit here and there thin limestones, sandy limestones, and calcareous sandstones, interspersed with other beds of purer sandstones and shales. South of the first fault lately mentioned there are seen ripple-marked sandstones and flags.

The calcareous sandstones are seen in Dry Beck rather more than half a mile above the village of that name. Ironstones and sandy plant-beds also occur here.

The "Little Strickland Limestone" is best seen in this area about Drybeck village, and high up on the slopes above Crosby Ravensworth. It is probably the same limestone as that which is called the Simonstone or Tyne-bottom Limestone in the region east of the Eden Valley. It is seen in the roads between Maulds Meaburn Edge and that village, but is concealed by drift till Bastern

Gill is reached. It is seen again at Hull's and in several places N.E. of Bank Head, where it is a dark grey crystalline limestone. Its southern extremity is reached near Howard's fault, which throws the rock down on the north-west a short distance. It takes a course rudely parallel to the fault for about a mile on the south side of it, but is in places completely concealed by drift. Where visible it is a grey crystalline limestone.

The limestone shows up well about Drybeck village and must be a fair thickness. It is dipping N.E. at 8° . I cannot say where this limestone extends E. of this point, nor could I identify it with any of those bands which are visible, the ground being much covered with drift as well as being faulted.

The Reagill beds, with a thin coal-seam, may be recognised above this limestone on the slopes above Crosby Ravensworth (where the coal has been evidently worked along the outcrop for a distance of over a mile at intervals), and below Maulds Meaburn ridge. Two coal-pits are also to be seen near the little southeasterly fault marked on the map at Maulds Meaburn Moor. According to Mr. Goodchild's notes, the seam was six inches thick, and so could hardly have been a source of much profit. A massive coarse speckled grit with much felspar occurs in this series west of the Howard's fault and east of Johnny Hall's Trees.

The Limestones of Johnny Hall's Trees, &c.—There now remain to be mentioned six limestones counting up to and inclusive of The Great Strickland or King's Meaburn Limestone (B.), which probably represents the Main Limestone of the Wensleydale Series, all of which may be seen on or about the ridge which runs north and south parallel to the Lyvennet. Mr. Dalton has only mapped continuously four limestones in the area of Reagill and Lowther, within the same horizons.

So far we may be pretty sure of the identification of the limestones we have described below the Reagill seam, which forms an important means of correlating the beds in the two areas. Of the remaining beds the two upper limestones are almost certainly the same, but we cannot correlate any of the remaining four with the limestones of Reagill and Lowther.

We may note these four limestones in natural sequence, as follows:—

- Grayber Limestone.*
- Brackenslack Limestone.
- Maulds Meaburn Edge Limestone.
- Johnny Hall's Trees Limestone.

The last two are seen in Brackenslack Lane and in Scattergate Gill, and the upper runs along Maulds Meaburn Edge with a strong freestone below it. Here it is dipping N. 30° E. at 7° to 10° . Again by Johnny Hall's Trees both are seen, the upper forming a flat east of the plantation. Further east they

* Mr. Dalton mentions the Grayber Limestone, though he has not mapped it continuously.

are both cut by two northerly faults, which drop the beds between them; and the extension of the Howareles fault still further east seems to affect these beds, which cannot be traced on the S.E. side of it with any certainty.

The Brackenslack Limestone, which is of a brown colour, crosses the road just above the farm of that name. A large *Orthoceras* was obtained in a little quarry near, by Mrs. McKenny Hughes, and corals abound.

From this spot the bed is covered with drift for about three-quarters of a mile, but spreads out on the surface in the angle between the Appleby and Maulds Meaburn roads, where several exposures and "pots" in it are to be seen. It appears to run down to the alluvial flat south of Dryevers, but beyond this I have been unable to trace it. Speckled sandstones and fine white sandstone occur above it in several places.

The Grayber Limestone ranges in colour from gray to yellow. It is often yellow and rather rotten at the base. It covers a wide area between its top and base, though probably it is not very thick. The beds are dipping at about 5° to the N.N.E. At Grayber it is a thin-bedded limestone and in some places it is distinctly encrinital. The valley running down from Dryevers to the N.W., forms its top boundary, and along here are several "wet weather springs," which form little cones of ejection, and from some of these a blue shale is thrown out.

The beds above the Grayber Limestone differ from many of the other Yoredale sandstones in their coarseness. Coarse stained grit may be seen above the limestone, half-a-mile north-north-west of Grayber, and in Little Beck north-east of it. These are considered by Mr. Goodchild to be equivalent to the "Blea Moor Grits" of the district to the south-east, and of the Quarry Hazel of the mining district of Alston. Somewhat similar grits may be seen on the south-west of Barras Hall, near the angle of the road west of Nags Head Inn and at the Inn itself. If those are all about the same horizon, it is probable that the limestone running S.E. from the Dryevers alluvium, is a continuation of the Grayber Limestone.

The next two limestones B. and C. of Mr. Dakyns's list, are almost certain to be the Main Limestone and the Undersett or Upper Undersett. The latter is a limestone with siliceous bands, and is seen in Little Beck with black shales above, full of fossil; but it is better exposed about a mile east of Grayber. Mudstones and cherty shales full of fossils occur immediately above it, and still higher are light purple micaceous coarse and fine sandstones, seen near Sideway Bank.

The Main Limestone makes a considerable spread, and has been much quarried. At Tresspotts it is a soft white crystalline-looking limestone. At Wormpotts, a "pot" near the top of it exposes a compact claret-coloured limestone. At the base to the S.W. the beds present a lenticular structure developed by weathering. At the quarries near Sideway Bank is seen a very rubbly nodular limestone, and at Greenslack is a yellow limestone apparently

dolomitized. The limestones on the other side of the Cracken-thorpe Hall fault near Hoff and Hoff Row are probably the same. The Limestone at Barras (Barwise) Hall is most likely the Undersett. Here and near Hoff Row as at Greenslack the limestone is dolomitized. At the top of the Main Limestone east of Sideway Bank a row of large "pots" some 25 feet deep occurs.

Sandstone is seen in the brook near Bewley Castle ruins, and beds of about the same horizon are worked at Bolton Quarry, south of Bolton Lodge for freestone. They are rather coarse along certain bands and somewhat felspathic. Clayey shales of grey and purple colour are to be seen higher up Teas Sike dipping beneath them. They are probably the same as those in Swinegill Sike mentioned at p. 95.

Sandstones of closer grain than those at Bolton Quarry occur about Burwain; these are beneath the shales just mentioned.

The Bewley Castle Limestone.—An interesting little scar of limestone skirts the northern flank of Teas Gill near Bewley Castle. It is a yellow nodular limestone with siliceous bands and crinoids. I also saw several fish-teeth in it. Mr. Goodchild says it is exactly like "The Red Beds" of Swaledale. It reminded me of a thin limestone which I found on the top of Mallerstang above the higher Eden Valley.

R. H. T.

MILLSTONE GRIT.

It is not easy to define the lower limit of the Millstone Grit in the valley about Appleby by reason of the absence of continuous sections, the number of faults, and the obscuring of the rocks by drift. The rocks under Battlebarrow and east of Whirly Lum are most probably of that series, but no definite line can be drawn between these and other rocks further west. The limits given by colour on the map therefore must not be regarded as anything more definite than a confession of our ignorance.

R. H. T.

Area north of the River Eamont.

BASEMENT CONGLOMERATE.

The Basement Conglomerate crosses the River Eamont from the south at the foot of Ullswater, and stretching westward between Bennethead and Hutton John to the edge of the area, forms a band of rolling hilly land culminating in the high round hills known as Little Mell Fell and Great Mell Fell, the two most striking features in the district immediately south of Penrindock and Troutbeck.

In the district extending from Ullswater south-east to Bampton, the conglomerate is, comparatively speaking, only thin, but at Great Mell Fell it attains a thickness of not less than 800 or 900 feet. (*See Hor. Section, Sheet 118.*)

The country occupied by it is mostly under cultivation, the fields showing a red pebbly soil; but good sections are to be seen at the south end of Little Mell Fell, at the foot of Ullswater, and along the course of Dacre Beck.

At the first-named spot the conglomerate may be well studied in a small cliff close to the faulted junction with the Lower Silurian rocks; here all the pebbles are of Upper Silurian sandstone or grit, some of them 3 feet long, and mostly lying with their long axes parallel to one another, though confusedly in some cases. At the foot of Ullswater, near Pooley Bridge, there is a capital lake-side section. There are many large blocks up to 3 feet in length, angular and sub-angular, with their long axes *generally* in the direction of the bedding of the finer stratified sandy matrix. The blocks are almost all sandstone and grit, but there are a few of a volcanic ash. Although some of the semi-rounded blocks have rather a glaciated appearance, the whole deposit is very different from the glacial drift seen in a roadside section close to the turnpike, in which the stones stuck in the clay consist *mostly* of ash.

In the course of Skitwath and Dacre Becks there are some good sections. In parts the conglomerate is of generally fine grain, containing no large blocks at all, and there is much false-bedding. I have already referred to the sections about Hutton as follows: "I have, in *Mell Fell*, found *no* undoubted instances of pebbles of trap or ash, though some of the small reddened and flaky pieces in the general matrix *may* belong to the Skiddaw Slate. At Hutton, however, two miles to the east, there are numerous pebbles of trap, ash, altered Skiddaw Slate, and limestone (probably Coniston) All this would seem to indicate that, after the removal in the Mell Fell area of a great thickness of the Silurian and volcanic rocks, so as to expose the Skiddaw Slate, facilities were afforded for the northward drifting of materials derived from Upper Silurian strata, while at the same time the neighbouring Volcanic and Skiddaw Slate beds were in part *protected* from denudation. Is it possible that the sandstone pebbles were drifted northwards around the skirts of a tract of high land, which, not rising in any lofty peaks, was effectually protected from marine and sub-aerial denudation, at that particular time, by an icy covering, leaving few or no rocks exposed above its surface? The pebbles of ash and trap in the Hutton deposit seem many of them to belong to the Eycott Hill series, which, lying outside the tract of high ground, may have been more open to denudation. Such a supposition as the above might partly account for the peculiar distribution of the materials forming the conglomerate, though it is evident that the *present* distribution of the formation, as a whole, is mainly due to denudation taking place subsequently, and *possibly* in great measure before the deposition of the first limestone beds beneath the milder Carboniferous sea."*

* Geology of N. part of Lake District (Sheet 101 S.E.), p. 76. See also Ramsay, *Phys. Geology and Geography of Gt. Britain*, Ed. v. p. 112.

In the midst of the conglomerate there are some interesting cases of intrusive basalt, along and near the roadside east of Little Mell. A roadside section close to the house called Folly, shows the conglomerate resting upon compact, blue, crystalline basalt, which is vesicular *around its margin*. The conglomerate appears hardened at the junction. In the small patch most to the north the vesicles in the basalt are some of them rather large and have been filled with very flint-like silica. The character of these basaltic intrusions—for intrusions they certainly seem to be—is not unlike that of the intrusive basalts among the Carboniferous Limestone series far to the north-east (Whin Sill, &c.) and may belong to the same period. The following is their microscopic character:—Minutely crystalline, small felspar needles interlacing; magnetite and chloritic matter between and among the needles; numerous chloritic pseudomorphs after augite and some apparently after olivine; vesicles filled with chlorite, calcite, and chalcedony.

J. C. W.

[The chief constituent is olivine in crystals often with good idiomorphic outline much altered to serpentine occasionally penetrated by green hornblende needles, but still absolutely unmistakeable in shape. In E. 78 these olivines are entirely replaced by yellowish green hornblende aggregates and quartz or a cloudy pleochroic product. The ground consists of well-twinned fresh needles of plagioclase set amongst very small granules of augite and iron-ores. The rock is of the usual late or post-Carboniferous olivine-basalt type.—W. W. W.]

The southern boundary of the area occupied by the Basement Conglomerate corresponds very nearly with the line of the Cove fault. It is partly a faulted and partly a natural boundary.

The northern boundary is mainly a natural one, the regular westwards trend of which is interrupted in places by faults. Except the two boundary faults surrounding the triangular area between Beckces and Whitbarrow Hall, none of it requires to be described at length.

The junction of the limestone and the conglomerate is seen near the top of the river bank on the north side of Skitwath Beck south of Penruddock. Here there is a whitish calcareous shale with hard nodules of limestone, between the limestone and the conglomerate. The upper beds of the conglomerate are fine and sandy, and they pass down gradually into beds composed of coarser material. The fragments are mostly angular and sub-angular, and the bedding very regular. It bears a striking resemblance to the Permian breccia which occurs at Walkmill east of Whitehaven. Bore-holes put down by the Moss Bay Iron & Steel Co., Lim., along the Skitwath Valley south of Beckces prove the continuation of the natural junction as far as this place, while to the north-west of Beckces it appears that the limestone is faulted against the conglomerate.

On the rising ground south-west from Beckside three Bore-holes were put down and a small shaft sunk with the following results:—

Easterly Bore-hole, No. 25 (L.).

				Ft.	In.	Ft.	In.
Surface soil and Drift	-	-	-	8	0		
Brown Shale	-	-	-	16	6		
Limestone	-	-	-	6	0		
						30	6

A small shaft was sunk a little lower down the hillside, and Mr. Geo. Innes informs me that the measures passed through were nearly as follows, but that a detailed account of the sinking was not taken:—

Section in Small Shaft.

				Ft.	In.	Ft.	In.
Surface soil and Drift	-	-	About	6	0		
Soft brown Shale and lumps of brown and black stone.			Limestone predominating				
at the base	-	-	-	16	0		
White Sandstone, very soft	-	-	-	20	0		
						42	0

In the two westerly Bore-holes conglomerate was found under the surface in both instances.

Farther north at the small brook which joins Skitwath Beck near the Old Limestone Quarry, and about 8 chains from the Beck, the results obtained from three additional Bore-holes are given below:—

South-Easterly Bore-hole, No. 28 (L.).

				Ft.	In.	Ft.	In.
Surface soil and Drift	-	-	-	4	0	4	0
Conglomerate	-	-	-	19	4		
						23	4

Middle Bore-hole, No. 29 (L.).

				Ft.	In.	Ft.	In.
Surface soil and Drifts	-	-	-	3	9		
Limestone	-	-	-	1	8	5	5
Conglomerate	-	-	-	6	0		
						11	5

North-Westerly Bore-hole, No. 30 (L.).

				Ft.	In.	Ft.	In.
Surface soil and Drift	-	-	-	7	0		
Sandstone and Shale	-	-	-	19	6		
Dark Shale	-	-	-	25	6	52	0
Conglomerate	-	-	-	4	6		
						56	6

In order farther to test the accuracy of the Bore-holes No. 28 (L.) and No. 29 (L.), trenches were dug on both sides of the small brook near the site of the Bore-holes. Under the surface soil, which was 1 ft. 6 ins. to 2 ft. thick, a whitish hard calcareous shale containing small fragments of soft red slate and nodules of limestone was proved to exist. It bore a strong resemblance to the bed, lying between the red conglomerate and the limestone, seen on the north side of Skitwath Beck south of Penruddock, and referred to above (p. 60).

From what has been stated it is evident that on the west side of the Beckes fault, the Basement Conglomerate occurs immediately under the surface, and that on the east side of this line there are some 40 or 50 feet of shales and sandstone. The positions of the Bore-holes are so near each

other that there is not space for the conglomerate to come up to the surface with the ordinary dip and rise of the strata and it must therefore be thrown up on the west by a fault.

Again there are more Bore-holes on the north side of the wall extending north-west from the small brook to the Cattle Shed.

Bore-hole, No. 31 (L.).

		Ft.	In.	Ft.	In.
Surface soil and Drift	- - -	6	0	6	0
Limestone, magnesian	- - -	3	0		
Sandy brown Limestone	- - -	1	0		
		<hr/>		10	0

Bore-hole, No. 32 (L.).

Surface soil and Drift	- - -	3	7	3	7
Limestone, magnesian	- - -	3	0		
Sandy brown Limestone	- - -	1	8		
		<hr/>		8	3

The limestone which is here called magnesian, is dolomitized Carboniferous Limestone. Limestone has also been found at Whitbarrow Hall. Traces of limestone are observable at the north end of the field south of Whitbarrow Farm-house. Red conglomerate occurs in the field north of the Penrith Road and east of the road leading to the Farm. From what has been stated above, it would seem that the limestone is thrown down on the north-west along a line indicated by the Whitbarrow Fault.

Besides the exposure of conglomerate on the north side of Swinescales Beck, already referred to in connexion with the Springfield fault (*see* p. 6), the basement beds are exposed on the Penrith road in the Plantation west of Whitbarrow Farm, and in the valley west of the road from Springfield to Berrier. Decomposed conglomerate was also seen on the road to Berrier, north of the road from Berrier to Greystoke.

R. R.

CARBONIFEROUS LIMESTONE SERIES.

Area south-east of the Kirk Rigg Fault.—The fault which has been called the Kirk Rigg fault is that shown on the map, north of and nearly parallel to the Penrith road, running in a north-east direction from Penruddock. It has a downcast to the north, apparently increasing eastwards. If the Red Hills Limestone be the same as that at Hoghouse Hill, which there is some reason to believe, it is thrown westwards from north of Belmont to Hoghouse Hill, a distance of nearly a mile, and therefore the fault here must have a large downcast to the north. At Penruddock it seems almost to have died out, for there is probably very little difference in the relative horizons of the beds north and south of the fault.

The ground is so obscured by drift that the exact position of the fault cannot be ascertained.

The section on the north bank of the Skitwath Beck south of Penruddock where the limestone is seen coming on naturally above the conglomerate has already been mentioned (*see* p. 62).

Immediately east of this the ground is obscure, but near Highgate the lower part of the Carboniferous Limestone Series forms two

features, and the strata are overlaid by quartzose sandstone, which has been pierced by a boring as follows:—

Bore-hole, No. 21 (L.).

					Ft.	In.	Ft.	In.
Surface soil and Drift	-	-	-	-	10	0	10	0
Sandstone and Shale-partings	-	-	-	-	17	5		
Sandstone	-	-	-	-	24	2		
Red Shale	-	-	-	-	1	0		
Red Sandstone	-	-	-	-	16	4		
Sandstone and Shale	-	-	-	-	15	3	74	2
Gritty Limestone	-	-	-	-	27	6	27	6
							<u>111</u>	<u>8</u>

This Bore-hole does not give the full thickness of the sandstone, as it commences below the base of the overlying limestone. The latter rock is exposed in the scar between the road to Hutton John and the Township Boundary. It is a dark limestone containing *Rhynchonella*. A Bore-hole in Robinson's field south of the Penrith Road proved the existence of two important beds of shale in this limestone.

Bore-hole, No. 67 (A.).

					Ft.	In.	Ft.	In.
Surface soil and clay	-	-	-	-	7	0	7	0
Dark Limestone	-	-	-	-	2	6		
Shale	-	-	-	-	4	6		
Sparry Limestone	-	-	-	-	7	1	14	1
Dark Shale	-	-	-	-	10	9	10	9
Limestone	-	-	-	-	2	2		
Shale	-	-	-	-	1	3		
Dark Limestone	-	-	-	-	3	3	6	8
Blue and White Shale	-	-	-	-	14	6	14	6
Limestone	-	-	-	-	4	9	4	9
							<u>57</u>	<u>9</u>

A band of grey clay, shown by a line on the map, separates the *Rhynchonella*-limestone from that next above.

Another Bore-hole at the north side of Robinson's field and near to the Penrith Road was put down through the lower beds of the upper limestone as follows:—

Bore-hole, No. 18 (L.).

					Ft.	In.
Surface soil and Drift	-	-	-	-	15	0
Limestone with thin Shale partings	-	-	-	-	22	6

Close by there is a small quarry on the south side of the road, in which the limestone dips apparently to the south-west.

In the fields north of the road at this quarry several Borings have been made. The most important of them is as follows:—

Bore-hole, No. 14 (B.).

					Ft.	In.	Ft.	In.
Surface soil and Clay	-	-	-	-	9	6	9	6
Shaly Sandstone	-	-	-	-	14	3	14	3
Limestone	-	-	-	-	10	6		
Shale	-	-	-	-	1	0		
Limestone	-	-	-	-	22	2		
Shale	-	-	-	-	6	0		
Limestone	-	-	-	-	16	0	55	8
Dark Sandy Soil	-	-	-	-	4	0	4	0
							<u>83</u>	<u>5</u>

The limestones above the quartzose sandstone are supposed to be on the same horizon as the Summerground Limestone further north, a bed regarded as the equivalent of the Melmerby Scar Limestone.

The beds just described are broken near Highgate, and also east of Dacre Bank, as shown by the shifting of the *Rhynchonella*-limestone; and the faults marked on the map are drawn to account for these displacements.

The fault near Dalemain is proved by the break in the escarpment of the limestone which forms the bank crowned by Elders Plantation. This band is believed to be above the *Rhynchonella*-limestone. The dip of the strata varies from 5° to 10° , and from N.N.E. to N.N.W.

The rocks above Elders Plantation and Eveningbank Wood consist of limestone with thin bands of sandstone and shale, and are exposed in several places, as the ground south and west of Stainton is nearly all bare rock. The overlying beds are well seen in the river-bank near the bend east of the village. The section is as follows:—

Blocky limestone forming the slope of the hill.
Thickly-bedded sandstone.
(Gap).
Limestone forming a scar.
Sandstone and flags, down to river-bed.

The highest bed in this series is well seen in several places, and has been quarried on both sides of the railway.

The overlying measures seem to consist mainly of sandstone, traces of which are of frequent occurrence in the fields hereabouts.

Next in succession comes the limestone seen at the Ford south of Red Hills:—

Sandstone.
Shale, 4 ft.
Limestone.
Sandstone.

Exposures in a railway-cutting near Red Hills and in the fields, enable us to map this limestone for some little distance to the north-west, but it is soon lost under the drift, or cut off by the Kirk Rigg fault. The sandstone between this bed and the limestone next above it contains fossils. It is seen in the river-banks south of Red Hills and also on the Penrith Road and in the railway-cutting at this place. The overlying limestone comes down to the River Eamont south of Skirsgill Hall and can be traced nearly as far as the sharp bend in the river between Skirsgill Hall and Eamont Cottage. It has a pink top and is encrinital; and it has been quarried on both sides of the railway.

Eastwards of the Permian area no rocks are seen except some small exposures of sandstone in the bed of the river. Various features trend across the country in the direction of the strike, but the character of the underlying rocks is not known.

Area north of the Kirk Rigg Fault.—The ground in the extreme north-west of the district is not very clear. Limestone occurs at Berrier just outside the map. A reddish sandstone, probably *in situ*, was seen at the source of Hatters Sike. East of Berrier a ridge consisting of two beds of limestone with a thin band of sandstone between them trends south-east. This rock is also to be seen in Hatters Sike east of Berrier End. The dip is towards the north-east, and varies from 8° to 12° .

East of Skitwath Beck many exposures of limestone occur throughout the district, and both quarries and bore-holes show that the rocks are alternations of limestone, sandstone, and shale. Thus a bore-hole in a quarry proved the following beds:—

Dark sparry Sandstone, 19 ft. 10 in.

Dark Sandy Shale, 16 ft. 7 in.

Dark Sandy Limestone, 6 ft. 8 in.

In a quarry north of Beckside, limestone is to be seen passing down into sandstone.

Red sandstone is seen near the south end of Moorslack Wood about half-a-mile west of Motherby, and two Bore-holes give the following sections:—

Bore-hole, No. 76 (A.).

In field close to south end of Moorslack Wood.

					Ft.	In.	Ft.	In.
Surface soil, &c.	-	-	-	-	1	0	1	0
Red Sandstone	-	-	-	-	27	4		
Shale	-	-	-	-	3	9	31	1
Limestone	-	-	-	-	2	2	2	2
							<u>34</u>	<u>3</u>

Bore-hole, No. 78 (A.).

Watering Place east side of Moorslack Wood.

Surface soil, &c.	-	-	-	-	4	0	4	0
Sandstone	-	-	-	-	3	0		
Shale	-	-	-	-	6	6		
Sandstone and thin partings of Shale	-	-	-	-	22	7		
Shale	-	-	-	-	2	0		
Sandstone	-	-	-	-	12	11		
Shale	-	-	-	-	0	6	47	6
Hard Gritty Limestone	-	-	-	-	4	6	4	6
							<u>56</u>	<u>0</u>

Penruddock stands on limestone which is probably equivalent to the limestone forming the crags at Summerground. In the railway-cutting east of Penruddock a thin sandstone is to be seen overlaid by another bed of limestone. This sandstone is probably on the same horizon as the band of hard sandstone which occurs in connexion with the limestones in Greystoke Park and at Johnby.* The overlying limestone is still further exposed in the railway-cutting and on the surface south of the railway. In

* Ward, Geol. N. part of Lake District, p. 47.

several instances the limestone is partially dolomitized. Eastwards towards the road to Greystoke, additional borings prove that the upper portion of this rock consists of bands of shale, limestone, and sandstone.

In Motherby Quarry the strata under the limestone were proved to be as follows:—

Bore-hole, Motherby Quarry.

						Ft.	In.	Ft.	In.
Shale	-	-	-	-	-	1	4	1	4
Limestone	-	-	-	-	-	6	9	6	9
Sandstone	-	-	-	-	-	8	5		
Shale	-	-	-	-	-	13	10	22	3
Limestone	-	-	-	-	-	49	0	49	0
Shale	-	-	-	-	-	5	0		
Limestone	-	-	-	-	-	2	0		
Sandstone	-	-	-	-	-	3	0	10	0
Limestone	-	-	-	-	-	15	6	15	6
Shale	-	-	-	-	-	9	9	9	9
Limestone	-	-	-	-	-	9	3		
Shale	-	-	-	-	-	1	3		
Limestone	-	-	-	-	-	2	3	12	9
						<hr/>		<hr/>	
						127		4	

At the north-west end of the wood north of Motherby there is an old quarry in a purple, finely-grained sandstone, mainly massive but in places flaggy or shaly, and occasionally containing *Stigmaria*. Here the rock dips N. 5° W. at 10°. The same sandstone is also quarried on the north-east side of the wood and at this place limestone is seen coming on above it. The limestone is also exposed in the old quarry near the north end of Moorslack Wood and in a quarry west of Barffs Wood, just outside the area. At this place the dip is N. 16° E. at 5°. A reddish sandstone and another limestone occupy the remainder of the area north of Motherby.

East of the road from Hutton John to Greystoke, a limestone which may be equivalent to that at Barffs Wood, occurs at Stafford Wood. In the railway-cutting at the south-west corner of the Wood, limestone is seen resting on sandstone. Here the beds are inclined at an angle of 10° in a N.N.E. direction. At the south-west corner of the Wood the rock dips N.N.W., and the exposure near the Old Limekiln shows a similar dip. Around Kirkbarrow the solid rocks are hidden under a covering of drift.

In some places on Division Moor sandstone has been quarried, and there are also several groups of swallow holes which probably indicate the existence of as many beds of limestone.

On the rising ground of Division Moor additional beds of sandstone and limestone are exposed, but it is almost impossible to trace them with accuracy, though in two instances their positions have been indicated on the map. The limestones and sandstone which occur at Fluskew Pike west of Newbiggin have been traced round the Pike from the Newbiggin road to the northern edge of the area. The dip ranges from 6° to 9° to north-west.

The Newbiggin fault has been inferred chiefly on the ground that the upper limestone at Fluskew Pike is believed to be equivalent to the limestone at Hoghouse Hill. There is great similarity between the beds on both sides of Newbiggin. It is therefore surmised that there is a fault throwing up to the east, and running close along the road through the village, but the fault has not been actually seen.

Limestone is seen in quarries south of the village and west of the road from Newbiggin to Stinton. This may be the same bed as the lower limestone at Fluskew Pike. Opposite Fauldhead and east of the village the sandstone there exposed is succeeded by a limestone, probably the same as the upper limestone at Fluskew Pike. This rock has also been quarried between Newbiggin and Hoghouse Hill, where the dip is in a north-east direction at angles varying from 8° to 10° .

The small remaining portion of this district is obscured by drift.

R. R.

Area near Milburn Grange.—In the extreme N.E. corner of the area there occurs a small isolated area of Carboniferous Rocks entirely surrounded by Triassic and Silurian rocks.

This area is supposed to be bounded by faults both on the east and west. The faults are not seen, as the country is very much obscured by drift; but are inferred for the following reasons. The Carboniferous beds undulate a great deal and strike against the Silurian rocks on the east, so that different members of the Carboniferous series abut in succession against the Silurian: this indicates a fault on the east side of the Carboniferous area bringing up the older rocks on that side. On the south and west the Carboniferous rocks are bounded by beds of the St. Bees Sandstone, which between Milburn Grange and Gullom Holme dip at angles of from 5° to 12° in a north-easterly direction towards the Carboniferous area. This again indicates a fault bringing the Trias against the Carboniferous. It is a continuation of the western Pennine fault.

In the adjoining area of map 102 N.W., soft red false-bedded sandstone believed to be Penrith Sandstone, is seen in Crowdundle Beck close to Carboniferous Limestone, but dipping towards the west so as to pass over the limestone. The actual junction of the beds is not seen: as far as the dip goes the Penrith Sandstone might pass over the Carboniferous rocks; but as the shales overlying the Penrith Sandstone come on very soon, the latter must either be faulted against the Carboniferous Limestone or be abnormally thin.

The Carboniferous beds consist of alternations of limestones, sandstone, and shale: the limestone greatly preponderates, so that the beds probably belong to the Melmerby Scar series. At a spot half a mile north of Milburn Grange, a thick bed of limestone is seen dipping south at 15° and 20° overlaid by calcareous sandstone; the sandstone is succeeded on the south by limestone

probably overlying it, and this limestone by sandstone still further south; but the ground is much obscured by drift, and moreover is just on the line of a fault seen at Howgill Castle to the north, so that we cannot tell exactly how the beds are related to one another. The section near Howgill Castle at the margin of the area is in descending order as follows: near Marblescar Well, thin-bedded red-stained limestone dipping at 30° W.S.W., thick-bedded crystalline gritty limestone dipping at 35° nearly in the same direction, sandstone, limestone just below Howgill Castle dipping W.S.W. at 50° , limestone at the Castle dipping N.N.E. at 15° apparently against sandstone, the dip of which is not clear; further N.E. more sandstone is seen dipping to the S.E. If correctly drawn the fault of Howgill Castle must be of considerable amount: but the ground is too obscure to permit of our being certain of anything.

J. R. D.

CHAPTER VI.

PERMIAN AND TRIAS.

THE RED ROCKS OF THE VALE OF EDEN.

These rocks consist in descending order of the following members:—

Trias	{ St. Bees Sandstone.
	{ Red shales with gypsum.
Permian	{ Magnesian Limestone and Plant Beds.
	{ Brockram and Penrith Sandstone.

For the sake of convenience these formations are considered together in one Chapter, although the lower strata are assigned to the Palæozoic group and the upper strata to the Mesozoic.

Before describing the rocks in detail we will say a few words about the boundaries between the Red Rocks and the older formations. Near Appleby these boundaries are complicated and in places faulted, and inliers of Carboniferous rocks occur in the valley of the Eden and elsewhere.

From Bolton Lodge north-westwards the actual junction of the Permian and Carboniferous rocks is not exposed in a single instance, unless it be at Lyvennet Bridge in the valley of the River Lyvennet, so that its position cannot be fixed with certainty.

Penrith Sandstone is very well seen at Lyvennet Bridge, in the west bank of the stream, and also in the east bank opposite Walk Mill. It also occurs on the south side of Morland Beck, at the bend where it turns to the east, south of Winter House. Pink-coloured limestone comes to the surface in Greengill south of Morland Mill. Here the dip is 5° to the north. Again at Force Bridge in the centre of Morland village, limestone is seen in Morland Beck dipping N.W. at 5° . South of Oliburn the pretty gorge of Trough Gill is cut out entirely in Penrith Sandstone. In this gorge the rock is worn out into caves and recesses covered with a beautiful growth of ferns. Near the upper end of the gorge thin beds of breccia ranging up to eight inches thick are contained in the sandstone. In Woodhouse Gill, thinly bedded soft red sandstone (Permian) is seen north of Woodside; and south of the same place, grey and purple micaceous flaggy sandstone (Carboniferous) is exposed. There is some doubt as to whether the variations in the dip at the last-named exposure are due to false-bedding or to contortion. Again in the valley of the River Leith south of Melkintorpe Hall, thinly-bedded micaceous sandstone is exposed at Burnbank Dubs, and sandstone is seen almost continuously on both sides of the valley until the limestone comes up in the river just north of the bend at Oldscar Wood. The beds

in this locality dip very uniformly about 5° to the N.N.E. North-westwards through Clifton there are neither features nor sections from which the position of the base of the Penrith Sandstone can be accurately determined. There is a good section at Hugh's Crag where the Lancaster and Carlisle Railway crosses the River Lowther, showing sandstone, shale and limestone, but the nearest places to this exposure of Carboniferous rocks where the Penrith Sandstone is known to exist, are at Low Dikes, where there is a quarry in false-bedded soft red sandstone, and in the gardens of Brougham Hall, where the rock is seen in the river bank on the south side of the alluvial flat of the Rivers Lowther and Eamont. The sandstone is at, or near, the surface along this bank all the way from Brougham Hall to Brougham Castle. The Penrith Sandstone does not appear anywhere in this portion of the River Eamont, but Carboniferous sandstone was observed in the bed of the river between Eamont Bridge and Southwaitegreen Mill. In a well on the south-west side of the occupation road leading from Great Dockray, in Penrith, and running parallel to the main road to Eamont Bridge, soft red sandstone (Penrith Sandstone) was found under a thin covering of gravelly soil. The situation at this well is close to, but just north of, the area under description.

It is evident from the description given above that the line forming the south-western boundary of the Penrith Sandstone through Melkinthorpe and Clifton, and also across the Rivers Lowther and Eamont, is one which cannot lay claim to absolute accuracy.

The north-eastern boundary of the Red Rocks is part of the group of faults west of Cross Fell which range from Brough-under-Stainmore, north-west along the base of the Carboniferous escarpment by Melmerby. So far as the present district is concerned there are no sections showing the actual position of the fault, but in Knock Gill it can be fixed within very narrow limits. Here a short distance north of the place where the path from Knock to Far Close crosses the brook there is an exposure of St. Bees Sandstone, dipping 10° to the N.N.W. This Sandstone is exposed on each side of the valley for a distance of about four or five chains. About two chains higher up the stream, flaggy shales, very much crushed and broken, are seen. They belong to the Coniston Flags. It is clear therefore that the fault must pass between the points above indicated, and it has been laid down accordingly. At the north-west end of the boundary south of Howgill Castle, the Carboniferous rocks strike both east and west, and north and south, against the St. Bees Sandstone lying on the north side of Milburn Beck.

Within the area lying between the boundaries above delineated the prevailing dip of the Red Rocks is towards the north-east, so that the lowest members of the group occur on the south-west and the highest members on the north-east side of the district.

R. R.

PERMIAN.

Brockram and Penrith Sandstone.

The rocks which are here comprehended under this designation comprise all the strata of Permian age up to the base of the Plant Beds. Throughout the area now being described these rocks undergo some very remarkable and rapid changes in their lithological character as they trend from the south-east towards the north-west. The two extreme types of development may be conveniently referred to as the Appleby or south-eastern, and the Penrith or north-western type respectively. The Appleby type consists very largely of breccias interbedded with subordinate bands of red sandstone. The Penrith type, occurring on the same horizon, is composed almost exclusively of massive red sandstones, undivided by shales, and, so far as is known, it does not contain any interbedded breccias. In the district between Appleby and Kirkby Stephen the Lower Permian rocks are of the former type, while the mass of red sandstones extending north-westward from Whinfell Forest represent the latter.

We will first describe the Permian Rocks as they occur near Appleby, where they consist of the following subdivisions:—

- Upper Red Sandstone.
- Upper Brockram.
- Middle Red Sandstone
- Lower Brockram.

J. G. G.

These rocks are well seen in the Eden banks about Appleby itself and about Great Ormside, also in the Hoff Beck Valley near Burrells.

It will be seen on the map that the areas occupied by Permian and Carboniferous rocks at their junction are more complicated here than they are in the country to the north-west. This is owing to the great spread of thick drift coming on to the north-west, which covers the rocks and necessitates a simple dotted conjectural boundary.

A little distance down the beck from Bewley Castle, red sandstone is to be seen, which appears of Permian character, and as there is no appearance of basement-beds it is probably faulted down against the Carboniferous rocks in this section. The fault seems to extend at least as far as Barras (Barwise) Hall and probably further through the Carboniferous rocks. It may not be a big fault although running so far, for throughout the greater part of its course the Brockram on the east of it is striking with it, and dipping easterly away from it. A small cross-fault appears to cut off the Permian at the south end of Knock Bank, near Barras Hall, but the natural base soon rises from it, and wanders down to the alluvial patch N. of Hoff Row. The Brockram is next seen resting on the Carboniferous near Bandle Wood and hence, on and above the right bank of Hoff Beck, it forms a fine series of

mural escarpments from under which the Carboniferous rocks rise, striking at an oblique angle. The dip of the Brockram is to the N.E. a little east, and the Carboniferous sandstone, shale, and limestone dip a little more to the north.

This long stretch of Brockram is ended by a small fault N.W. of Burrell's Moor House and is lost beneath the Glacial Drifts. It is interesting to note that the Brockram along here instead of being composed almost exclusively of fragments of limestone, as is usually the case, contains abundant pieces of Carboniferous sandstone. This is only to be expected in a basement-bed which is here in near proximity to the Millstone Grit.

Although the western boundary of the Permian rocks may be thus accurately described, we find exposures of Carboniferous sandstone and shales to the east of it in several places. For instance, at the bend of the Eden near Crackenthorpe Hall we have fine salmon-red sandstone dipping W.S.W., which seems to be a Permian sandstone overlying the Brockram—but it is faulted against coarse Carboniferous sandstones which are dipping east at 25°. The fault seems to be running between S. 10° E. and S. 20° W., probably the former. This will take it along the little valley running west of and parallel to Hoff Beck, and give a western boundary to the inlier of Carboniferous rocks.

Hoff Beck gives many exposures in the latter, but the existence of Brockram in the bed north of Bandle Bridge gives a southern limit to the Carboniferous inlier in this direction. The base of the Permian is concealed by drift east and west of this point between the fault already mentioned and another yet to be described near Appleby.

Close to the junction of Hoff Beck with the Eden, Brockram may be seen dipping to the north-east at 10°; and at a position corresponding with the strike of this, close to the Eden at the north end of "The Banks," where the river crosses over to the other side of the alluvium by a turn called Whirly Lum, Brockram is again seen dipping E.N.E. and overlying the Carboniferous grits. Inasmuch as the opposite banks of the river and those for some distance to the north show Carboniferous rocks, there seems to be at least a strong probability of a fault running in a line from one to the other of these sections, and bounding the Permian in the east. This may be considered therefore a faulted outlier in the Carboniferous inlier. In the bed of the river and in the banks between the Appleby Gas-works and the Penrith road, Brockram is to be seen. Carboniferous rocks are absent unless some rock in a deep pool which was always under water and inaccessible represents them. The north-eastern boundary of the inlier may be therefore either a fault or a natural base. Its course is conjectural, being hidden by Glacial Drift. The same may be said for the fault bounding the inlier on the north.

Brockram is also seen in the Penrith road a little below the Friary. A sandstone like the Penrith Sandstone comes on at a lower level in the same road, and may be seen at intervals on the east side of the river and the road as far as Bongate.

There is probably a fault, between the two first mentioned points, which runs in the direction of "The Banks," and being a downthrow on the south-east may form the boundary between the Carboniferous and Permian rocks. This is almost a certainty, because although opposite Castle Bank and beneath the Castle we have Brockram passing under the red sandstones with a north-easterly dip, it does not appear again, and the next rocks on the north are Carboniferous.

A small fault running across the Eden may be seen opposite to Castle Bank with a downthrow to the N.W. It drops the red sandstones against the Brockram.

Another fault, which is running parallel to the Eden and enters the area with it east of Burrells, throws red sandstone on the east against Brockram on the west, and has therefore a downthrow on the east. It appears to be running in the direction of that described by the mouth of Hoff Beck and Whirly Lum, but if it is the same fault it has here a reversed throw, a not very uncommon circumstance.

A second inlier of Carboniferous rocks may be seen on the Settle and Carlisle Railway west of the road to Brampton. Castrigg lies west of it. Brockram occurs on the side of the cutting just north of the crossing of the Roman Road, but this rock and the features made by it gradually recede from the railway as it runs north. Carboniferous sandstones and shales however are visible in the cutting for some distance; they appear to be dipping N. 35 E. at 15° to 20°. There is at least one strong grit with shales above and below it.

The limits of this inlier are entirely conjectural. It may be faulted on the western side. Probably there are many more faults running in the same direction on the east side of the Eden. If it were not so we should have a much greater thickness of Brockram than the clearer sections in the neighbourhood would warrant us in assuming. But the ground being very much covered with drift, there is little chance of obtaining more definite information.

Where the road from Appleby enters the ground on which the annual fair is held, Brockram is to be seen, but near by I found some traces of shale turned up. I thought at the time that it might have been brought up a bore-hole, and Mr. Goodchild now informs me that this was the case.

R. H. T.

Lower Brockram.—Perhaps the best sections in the Lower Brockram are those situated right and left of the road between Burrells and Hoff, where this rock has been extensively quarried for building-purposes.

In the Burrells Quarries the superficial aspect of the Brockram reminds one strongly of the type of Carboniferous limestone prevalent in the adjoining district. It is very evenly bedded, it occurs in thick "posts," it is very regularly jointed, and its colour is identical with that of many of the iron-stained limestones so common in the neighbourhood. Moreover, as the rock contains a large per-centage of limestone fragments, which form about nine

tenths of the rock, its mode of weathering naturally follows that of the rock from which its predominant constituent has been derived.

When looked at more closely, however, the Brockram is clearly seen to consist of an aggregate of fragments, more or less angular in form, which are bound together by a cement of calcareous sandstone. The materials range in size from that of mere grains up to blocks two, or three, feet in diameter. The predominating size, however, may be said to be about two inches. There is not any very clear evidence of sorting of the materials in regard to either size or form, as big blocks and little are promiscuously associated, much as they are in boulder clays. The stones, however, usually lie with their longer axes parallel to the bedding planes. This fact would suggest a sub-aqueous origin for the rock in this case, aided perhaps by the distributing action of shore-ice. Anything approaching a veritable glaciated (as distinguished from slickensided) stone has been sought for in these rocks for many years, but usually in vain. But during the visit of the Geologists' Association to Stank Quarry in 1889 the late Mr. Wm. Atkinson, B.Sc., of Knock, obtained from the solid rock of this quarry an unmistakeably glaciated limestone-boulder, which was examined by the whole party, and about the glacial origin of which no one present felt any doubt.*

At irregular vertical intervals the strata (or "posts") are separated by thin and very inconstant beds of calcareous sandstone, of the same nature as that which forms the cement of the rock, and which are, like this cement, of a pale copper-red colour. In respect of this, these thin partings resemble the Penrith Sandstone, and may be regarded as the thin ends of sheets of sandstone which gradually swell into beds of greater importance as the strata trend towards the north-west, and eventually take the place of the Brockram entirely. Taking it as now the generally-accepted view that the Penrith Sandstone is mainly a desert sand, and therefore of eolian origin, the layers in question may be regarded as inter-stratifications of blown sand amongst the lacustrine equivalents of that rock.†

The dominating constituent of the Brockram, here and elsewhere in the district, is unquestionably limestone, which forms from eighty-five to fully ninety per cent. of the rock. Of the remainder about five or six per cent. consists of sandstone of Carboniferous origin, together with some derived chert, and a little shale. Here and there occurs a pebble of liver-coloured quartzite, which we should probably be correct in regarding as having been derived from some older conglomerate. Fragments of Whin Sill have been carefully sought for; but hitherto without success. Nor have any traces of the rocks of the adjoining Lake District as yet been found here. Hardly any of the constituents of the Brockram remain in what must have been their original mineral condition.

* Proc. Geol. Assoc., vol. xi. p. xciv.

† See Goodchild, Trans. Cumberland Assoc., No. ix., 1885, p. 31.

The limestone-fragments are dolomitized in various degrees; some appear to be hardly, if at all, changed from their original condition, while others are entirely re-crystallized throughout, or are affected so much by the change of dimensions consequent upon their alteration into dolomite, that they are full of drusy cells and cavities, which are frequently lined with crystals of pearl spar. Some other limestone-fragments are affected in a different way, and are partially, or even entirely, replaced by impure hæmatite, the original form of the limestone-fragment remaining, apparently, quite unchanged. Fragments of limestone of an arenaceous or of an argillaceous character, such as occur in the the Carboniferous rocks adjoining, are occasionally changed in colour from the original grey to bright red. The fragments of Carboniferous shale, and of sandstone, are usually altered in a different way. The light mica of the sandstones is altered into a plum-coloured mineral compound, which seems to pass in some instances into hæmatite; while the sandstone-matrix is itself stained various shades of dull purple, puce, or even of brighter tints of red, if the rock happens to be at all calcareous. Fragments of shale are affected in the same manner, though they exhibit a decided tendency to pass into tints of pale lilac, or puce.*

Breccias of essentially the same character as those described in connexion with the quarries at Burrells are well displayed at several other localities south of the River Eden. A good exposure may be examined near Barwise Hall about two miles south-west of Appleby, and in several little quarries and natural exposures to the north of that, as far as Penny Hall. This rock is again seen near the junction of Colby Beck with the Eden; and also nearer Appleby, at Thistley Hill; as well as in various small exposures connected with the rock worked at Burrells.

At all the localities mentioned the rock is mainly the lower part of the Lower Brockram. As the prevailing dip on the whole is towards the north-east, higher beds tend to come on in that direction; but the combined effects of faults and the local variations of dip, repeat the strata and keep the lower beds near the surface over most of the area to the south-west of Appleby. In the Eden below Appleby Castle, however, what are probably the highest beds of the Lower Brockram are well exposed. The lowest beds seen consist of breccia-conglomerates of the kind already described; but, perhaps, on the whole, rather less dolomitic in character than they are elsewhere. These are succeeded by alternations of thin bands of breccia with breccia-sand-

* The replacement by hæmatite of the original calcareous constituents of the fragments included in the breccia has in some instances proceeded so far as to make it appear at first sight that the Brockram includes veritable fragments of hæmatite, and hence that the hæmatite must be older than the Brockram, instead of owing its present mineral character to changes brought about at a later date. The change referred to is often well displayed in hand-specimens, and there are some in the Museum of Practical Geology that well illustrate the point in question. It may be worthy of remark that, among the various stages of alteration from dolomitized limestone into hæmatite no noticeable trace of carbonate of iron has yet been detected in the cases mentioned.

stones, resembling to a great extent the sandstones seen at higher horizons, but containing a variable per-centage of limestone-fragments scattered irregularly through the mass. These fragments are of all sizes from small stones up to pieces eighteen inches in diameter. These alternations clearly indicate the transition to the next subdivision above. The dip of these rocks is on the whole towards the north-east, so that it is possible that these breccias may pass naturally beneath the section of red sandstone seen a little lower down the river in that direction.

Red sandstones again are seen in close connexion with beds of breccia believed to be high up in the series in Sweet Milk Sike, just below the ruins of Bewley Castle; but whether there is a natural transition here, or whether the line between the breccias and the red sandstone is in this case a faulted one, cannot be determined with certainty.

On the north side of the Eden, near Appleby, some faults of large throw bring the Lower Brockram again to the surface, and even the Carboniferous rocks below it are exposed in several places. A small section of these beds is exposed on the north side of the Eden Valley Railway just N.W. of Appleby Station. Another exposure may be easily examined on the north side of the Roman Road near Gallows Hill, rather less than a mile N.N.W. of Appleby Church. But the best sections are those displayed in the Brockram Quarries at Stank, a short distance to the east of Gallows Hill, and about three-quarters of a mile N.N.E. of Appleby.* In regard to the lithological character of these beds they do not differ essentially from the beds already described in connexion with Burrells. There is here, however, a much higher dip, which ranges between ten and twenty degrees towards the N.E. Prof. Harkness found that bore-holes were put down through these beds in this neighbourhood, and the presence of Carboniferous rocks immediately below them clearly proved. There can therefore be no doubt that these breccias at Stank and the other places near represent the Lower Brockram brought up by faults, and that they are not the representatives of the Upper Brockram, as their position in relation to the Brockram on the south side of the Eden has led many persons to suppose. The shape of the ground along a line ranging north-westerly through Hungriggs, on the dip-side of the quarries just referred to, suggests that the breccias terminate upwards in the Middle Sandstone, just as they seem to do at Appleby Castle; but the evidence is too scanty to admit of any certainty upon this point.

The only other exposure of the Lower Brockram that need be mentioned is a small, and not altogether satisfactory section that, during the construction of the Midland Railway, was laid bare at the north end of the Castrigg Cutting, between Appleby and Long Marton. Its mode of occurrence in relation to the Carboniferous rocks exposed in the same cutting, nearer Appleby, seems to indicate that it actually represents the very base of the

* See *ante* p. 75.

Lower Brockram, which, if that were the case, would here come on naturally above the Carboniferous Grits.

Middle Red Sandstone.—Turning now to the Middle Sandstone of the Appleby type of succession, we find some excellent and easily examined exposures on the north side of the Eden at Appleby. One of the finest of these is that seen opposite Appleby Castle, where the rock has been quarried to some extent for building-stone. Another section is presented by a deep quarry amongst the houses just north of Bongate Mill. But the section most easily examined is that exposed by the road-cutting at Drawbrigg, Bongate, just east of the old Gaol. Here the rock consists of moderately hard, thickly bedded, red sandstone, varying in tint from pale copper-colour to venetian red. The most noticeable feature about the rock, here, as nearly everywhere else, is the prominence of the features produced by false-bedding. From top to bottom not a trace of anything that can be trusted as a plane of normal bedding can be seen; the whole rock consists of a pile of lenticular masses and curved wedges of red sandstone, each mass showing more or less evident signs of scooping and other forms of contemporaneous erosion. Extended observations upon the directions of false-bedding in the rock show that there is a marked predominance of false-bedding planes inclined, in a general way, from some easterly point towards the west. On the assumption that the Penrith Sandstone is of eolian origin, this westerly false-bedding may indicate the prevalent direction of the winds during the dry seasons.

The rock is almost exclusively a sandstone; beds of shale in this part of the formation being rare or absent altogether. In composition this sandstone presents some features of considerable interest. It consists of an aggregation of small sub-angular and well-rounded grains of quartz, generally coated by a thin film of hematite, which seems to act to some extent as the cementing material of the rock. With the quartz grains occurs a variable percentage of mealy-looking grains of small size, which are probably fragments of some felspar more or less kaolinized, though other minerals in a state of decomposition may also be present. But the strangest feature in connexion with this rock is the conspicuous absence of any noticeable percentage of mica. In this respect the rock under consideration contrasts strongly both with the St. Bees Sandstone, and with the sandstones of the Carboniferous rocks beneath. In the rocks last-named, mica, in some form or other, can always be detected. Quartz of secondary origin has crystallised upon many of the sand-grains: perhaps the silica thus deposited may have been partly derived from the decomposition of the mica, which is now absent, as well as from the felspar-grains already referred to.

No reliable estimate of the thickness of this sandstone can be made, as, apart from any other considerations, the rocks are cut off by faults, and nothing like the thickness exposed in Helton Beck is seen in any continuous section here.

Upper Breccia, or Brockram, and Upper Red Sandstone.—In the direction where this higher bed should come on above the Brockram, at Stank, no satisfactory evidence of the precise nature of the rock is forthcoming. The form of the ground does not help much, on account of the rock-features being masked by drift. But the red and sandy character of the soil at points where the drift is thin may be taken as evidence of the nature of the rock beneath. There can be little doubt that a considerable area on the dip-side of the Stank Brockram as far north as the woods at Flakebridge, is occupied by the remaining three subdivisions of this member of the Permian series. At Brampton a small lane in the middle of the hamlet, leading northward to Mill Beck, exposes a section in the higher part of these beds. The lowest bed exposed consists of red sandstones of the type just described as occurring at Bongate, but here containing one thin band of breccia, like the very top beds of the Upper Brockram exposed in Helton Beck. This sandstone is succeeded on the north by a thick series of friable, half-consolidated, flaggy sandstones of a bright red tint. Rocks of this kind are well exhibited behind the Old Smelting Mill a mile south of Dufton. The same crumbling, friable, red sandstone may also be seen at several places in and around Long Marton. There can be little doubt that the soft sandstone just referred to represents the highest member of the Penrith Sandstone Series.

Westward of a line joining Bewley Castle and Brampton, the exposures of Penrith Sandstone are confined almost exclusively to red sandstone of one or other of the two types before mentioned. This arises mainly from the fact of the rapid replacement of the Breccias, in their trend westward, by the thickening of the seams and beds of red sandstone described as occurring in connexion with the breccias near Appleby. The reason of the non-exposure of the Lower Brockram west of Bewley Castle, may possibly arise from the fact that the boundary thence north-westward for a few miles is faulted, so that the lower beds are concealed. The Lower Brockram has, almost certainly, not died entirely away, for in a gill rising south of Cliburn, what is probably the very top of the lower member of this series is represented by a few feet of Brockram of the ordinary kind, which passes up into Red Sandstone of the Bongate type, and forms the picturesque little gorge known as Trough Gill. Elsewhere the whole of the rocks belonging to this subdivision consist exclusively of red sandstones, of essentially the same type as those described in the Bongate section.

From Appleby north-westward for a few miles the soft half-consolidated type of Penrith Sandstone prevails, though harder beds do occur here and there. But north of Cliburn rocks of a more compact character begin to occur in force, and to prevail throughout the whole of their extension towards the north-west. It is this difference in the proportion of hard and durable beds to those of a soft and crumbling nature that gives rise to the distinctive physical character of the hills of red sandstone that form the surface in the northern part of this area, when compared

with the tame and featureless aspect of the scenery prevailing where the softer sandstones predominate.

A good section of these softer sandstones may be easily seen, even from the railway-carriage, at Cliburn Station (Eden Valley Railway), where the bright copper-red tint and the characteristic false-bedding of this rock are very well displayed.

Some of the harder beds of the Penrith Sandstone, especially in the district around Penrith itself, contain a variable percentage of doubly-terminated six-faced pyramids of quartz, with well-defined, and usually very bright, faces. It is the presence of these crystals that imparts the sparkling effect to so much of the stone quarried at Whinfell and in the hills to the north. Secondary quartz, as already noted above, occurs also near Appleby, and, in fact, nearly everywhere in the Penrith Sandstone; but it is much more abundantly developed around Penrith itself. Microscopic examination shows conclusively that this crystalline form is due to the deposition of secondary quartz around nuclei formed of rounded grains of sand. Some of the angles of the quartz crystals seem to have undergone attrition before they finally settled into their present resting places. The film of hæmatite that coats most of the grains, extends over both the worn and the unworn parts of the crystals.

The upper limit of the Penrith Sandstone is nowhere well-defined within the area. The only instance in which its exact position was ever actually proved was in connexion with the gypsum-workings at Kirkby Thore, where the gypsum at one place actually extended down to the top of the sandstone beneath. The top bed was red, instead of being fulvous or saffron-coloured, as it often is in the area to the east of this (102, S.E., new series, sheet 31). And, on the other hand, it did not exhibit that peculiar quartzitic appearance so characteristic of the beds on this horizon for some distance to the north.

J. G. G.

PERMIAN AND TRIAS.

Shales with Gypsum, Magnesian Limestone, and Plant Beds.—The boundary between the Plant Beds, or between the Magnesian Limestone, and the Penrith Sandstone is very uncertain. It is rarely that the junction between the two is either exposed or proved, and the division between the Plant Beds and the Red Shales cannot be definitely traced. In addition to this, the district where these beds exist is generally covered by Glacial Drift, and the surface-features are due to sub-aerial denudation of the drift rather than to any change in the nature of the underlying strata.

The shales themselves are exposed in some of the brook sections and in some of the pits in the neighbourhood where gypsum has been, or is now being, worked. On the strength of these exposures, together with such evidence as the surface supplied, a line has been laid down across the country between the Old

Smelting Mill, near Dufton, and the valley of the Eden, west of Newbiggin (Westmorland). This line represents with some degree of accuracy both the base of the Plant Beds and the top of the Penrith Sandstone.

Close to, but just beyond the eastern edge of the area, red and yellow sandstones and shales with carbonaceous matter are seen in the south bank of Burthwaite Beck at the west end of Flakebridge Wood, while near to this place, and within the map, the upper beds of the Penrith Sandstone occur in Rheabower Wood on the north side of the Beck. The junction of the Penrith Sandstone with the overlying marly shale is exposed at the south end of Park Brow on the west side of Mill Beck Valley. Northwards the steep sides of the valley are obscured by slipped ground and no continuous section can be seen. West of Stamp Hill the base of this subdivision of the Permian is approximately defined, because in the Gypsum Pit on the south-east of the road known as Long Rigg, Penrith Sandstone was proved to lie immediately under the bed of gypsum which was formerly worked there. And in the extensive old quarries on the north-west side of the road, gypsum occurs below shales probably the equivalent of the Plant Beds. At Pott's Well, near the Parish Boundary between Newbiggin (Westmorland) and Long Marton, red shales containing beds of gypsum, ranging up to 1 foot 6 inches in thickness, and also subordinate beds of sandstone have been proved in the old pits there. The Acorn Bank Gypsum Pit furnishes the next evidence whereby the position of the top of the Penrith Sandstone can be approximately fixed. The section exposed was as follows:—

Section at Acorn Bank Gypsum Pit.

	Ft.	In.
Red Shale with bands of soft yellow Sandstone	-	-
Blue Shale with vegetable remains	-	-
Red Shale	-	-
Blue Shale with vegetable remains	-	-
Gypsum in massive beds, uneven top	-	15 to 20 0
Red Sandstone, very tough and hard, proved under Gypsum	-	-

Red Shales with thin bands of hard sandstone were found under the drift in the deep cutting for the Midland Railway (Settle and Carlisle Branch) north of Crowdundle Beck, and red sandy shales with subordinate beds of sandstone, lying in a nearly horizontal position, are seen on the north-west side of the Beck near Newbiggin Bridge.

R. R.

The Magnesian Limestone division and the associated Plant Beds are very imperfectly represented here, as compared with the rocks of the same age in the district to the east. Indeed, the Magnesian Limestone itself does not appear to occur at all. The evidence at present available will not enable any definite opinion to be expressed as to whether this is due to a rapid westerly

attenuation of all the rocks on this horizon, or whether it is due to the removal of these rocks by denudation prior to the deposition of the Red Shales that come on next above. It is possible that the small thickness of beds seen in this area, as compared with their much more complete development in the area immediately to the east, may be due to a combination of both these causes. The highest Permian strata represented, pertain to the Plant Beds, which consist of a variable series of beds of maroon, pale glaucous, and dark grey clays and shales, with thin bands of magnesio-calcareous sandstone, usually of various shades of fulvous, and with occasional thin bands of impure magnesian limestone, and a little lignite. The whole series in this area nowhere much exceeds twenty feet in thickness, and in this respect these beds offer a remarkable contrast to their equivalent strata in the area to the east, as, for example, in Helton Beck.

Here and there throughout the grey clays, as well as in the fulvous sandstones above referred to, occur carbonized fragments of vegetable remains, nearly always too imperfectly preserved to admit of identification. They may be collected in tolerable abundance at Mr. Boazman's quarry at Acorn Bank; but they may be met with wherever the Plant Beds are exposed. The thin bands of magnesian limestone, which occur in the Plant Beds frequently contain small cavities whence crystals of selenite have been dissolved out—a result which is probably due to the action of water charged with organic matter.

All the gypsum worked in this district occurs between the top of the Penrith Sandstone and the base of the St. Bees Sandstone. It is by no means confined to any definite horizon within the vertical limits mentioned. It may, however, be described as generally occurring in this neighbourhood, on, or about, the horizon of the Magnesian Limestone and the Plant Beds. In the large pits worked just to the north-east of Kirkby Thore Town Head, the gypsum extends, as already mentioned, down to the Penrith Sandstone itself; near Stamp Hill, it occurs well up in the Red Shales that overlie the Plant Beds, and at a geological horizon perhaps as much as fifty or sixty feet higher than it does at the pits first named. It is most important to note here that these Cumberland and Westmorland deposits of gypsum occur at a very much lower geological horizon than the gypsum deposits in the Midland Counties, and agree in position with the gypsum and rock-salt of the Middlesborough district.* The Midland deposits occur in the Keuper Marls, strata lying above the St. Bees Sandstone where the succession is complete.

The gypsum usually occurs in one main bed, which occasionally attains a thickness of twenty feet. It is commonly accompanied by a variable number of thinner beds, worthless for commercial purposes. The thickness, is however liable to considerable variation, due, apparently, quite as much to original irregularities of deposition, as to subsequent removal by solution in water charged

* See also E. Wilson, *Quart. Journ. Geol. Soc.*, vol. xliv. p. 761.

with organic matter. The effect produced by the last-named cause can be very well studied in nearly every pit where this mineral is being worked. The upper surface of the gypsum is furrowed and eroded often to a depth of several feet, much after the same fashion as in the case of a mountain torrent which has drilled out pot-holes and caldrons in its bed, more particularly when the water flows in a channel cut out of the limestone-rock. Some of these pot-holes traverse the entire thickness of the gypsum, and leave a mass of clay in the place formerly occupied by the hard rock. In addition to the irregularities of bounding surface arising from the causes just mentioned, there are others whose relation to the gypsum on the one hand and to the enclosing rock on the other, seem suggestive of action of another kind. The clays and marls overlying the main mass of gypsum are traversed in all directions by thin veins and irregular seams of the same mineral; and the proportion of gypsum occurring in this manner increases as the main mass is approached. Some of the upper protuberances on the surface of the gypsum manifestly show that the bedding of the shale adjoining is continued without interruption through the mass of gypsum, just as the lines of bedding of the Chalk may be traced uninterruptedly through some nodules of flint. It is probable therefore that the dissolution of the gypsum interspersed through the overlying rock, and its re-deposition at a lower level, has locally brought about an irregular intergrowth which has, in places extended downwards to, and become united with, the main mass.*

The gypsum is nearly everywhere well-jointed. Good sections may be examined at the quarries near Kirkby Thore, and at Acorn Bank, near Temple Sowerby; while a good natural exposure, showing the gypsum in the condition of aggregation of lustrous satiny fibres, may be seen in the Red Shales on the south bank of the River Eden at Winderwath.†

J. G. G.

TRIAS.

The Triassic rocks include the following divisions:—

2.—St. Bees Sandstone.

1.—Red Shales with Gypsum.

It has been already stated (p. 80) that it is practically impossible in this district to separate the equivalent of the Plant Beds and the Magnesian Limestone from the Red Shales; and we have now farther to observe that the passage upwards from the Red Shales to the St. Bees Sandstone is generally so gradual that there is, strictly speaking, no well-marked horizon where the one may be said to end and the other to begin.

The Red Shales enter the district from the east on the north side of Burthwaite Beck near Dufton Wood, and follow a north-

* See Goodchild, Proc. Geol. Assoc., vol. x. p. 425.

† See also Harkness, Quart. Journ. Geol. Soc., vol. xviii. p. 209.

westerly course across Mill Beck, Keld Sike, and Crowdundle Beck to the northern edge of the area. They occupy a strip of country, about half-a-mile broad, extending from east of Long Marton to west of Newbiggin (Westmorland).

At the north end of Park Brow and almost opposite to the place where a new Bridge over Mill Beck has been erected, the following section was observed on the west side of the valley, a short distance below the horizon which has been taken as the base of the St. Bees Sandstone in this neighbourhood :—

	Ft. Ins.
Soft decomposed Red Sandstone - - - - -	
Fine Breccia with numerous fragments of quartz and limestone - - - - -	} 3 0
Soft Red Sandstone - - - - -	

Here the dip is N. 15° E at 19°.

North-west of Mill Beck the next exposures of the Red Shales occur in Keld Sike. At Stamp Hill, they are well exposed on the north side of the valley, and on the south side of the valley, near the same place, there is an Old Pit where Gypsum has been worked. Farther east there are Red Shales with sandstone-bands seen on the north side of the stream, and just above where the valley again takes a northerly direction, the St. Bees Sandstone is exposed on the west side of the brook. At this point, therefore, the position of the probable junction of the Red Shales and the St. Bees Sandstone can be ascertained within certain limits.

Between Newbiggin Bridge and the point where Milburn Beck joins Crowdundle Beck the Red Shales are not exposed, but the deep gorge at Millpark Wood through which Milburn Beck flows, is cut out entirely in St. Bees Sandstone. Throughout most of the district between Keld Sike and Crowdundle Beck the boundaries delineated on the map are very uncertain. The Glacial Deposits hide the solid rocks and render any physical features they may form so obscure that neither the top of the Penrith Sandstone nor the base of the St. Bees Sandstone can be determined with much accuracy.

R. R.

1. *Red Shales with Gypsum*.—With the exception of some small exposures seen here and there beneath the glacial drift in the Midland Railway-cuttings south-east of Newbiggin, and of some equally unimportant sections connected with the workings for gypsum, the beds on this horizon only appear in the north banks of Crowdundle Beck, just above Acorn Bank, and in the fine sections exposed in the adjoining cuttings on the Midland Railway.

The beds consist of venetian-red shales, which are occasionally interbedded with thin flags of the same colour. Near their upper limit the Red Shales everywhere pass by insensible gradations into the flaggy beds of the St. Bees Sandstone above; and there can be no doubt that they should be regarded simply as the shaly base of that rock.

A common feature of the Red Shales is the occurrence, here and there throughout the whole series, of spots and decoloration-marks of a pale-green tint. All the sandy bands, and much of the more argillaceous part also of this rock, contain more or less detrital mica, a constituent that has been already mentioned as very rare, or almost entirely absent, in the Penrith Sandstone below.

No trace of anything like fossils has yet been detected in these beds; though obscure markings, that may represent ichnites of some kind, have occasionally been found. Ripple-marks occur upon the faces of bedding of these shales; and occasionally more satisfactory evidence of their shallow-water origin may be found in the shape of desiccation-marks. The total thickness of the Red Shales in this area probably ranges between two hundred and three hundred feet; though there is no means of determining this point with certainty.

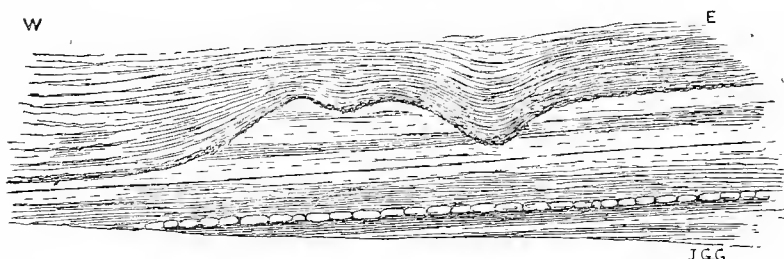
As a rule the beds next below the St. Bees Sandstone consist almost exclusively of Red Shales with thin bands of micaceous sandstone; anything like the coarse fragmental beds seen in the sandstone-series below being conspicuous by their absence. But on the north-west of Mill Beck, about midway between Dufton and Brampton, a thin band of calcareous breccia-conglomerate emerges from beneath the St. Bees Sandstone. The section where this exposure occurs is not very clear, and the distance of this conglomerate below the lowest exposure of the St. Bees Sandstone cannot be estimated with any certainty. The comparatively high dip prevailing in that neighbourhood would leave room for about a hundred feet, but there might be more than that. The rock consists of a series of stratified bands of breccia-conglomerate alternating with soft red sandstone and sandy shale. It is made up of well-rounded pebbles of quartz, ranging up to the size of a filbert, with a few sub-angular fragments of limestone, and of some other indeterminable rocks, bound together by a calcareo-arenaceous paste of much the same nature as that of the Brockram below. Whether this conglomerate marks the horizon of a small stratigraphical break or not is a point that, with the evidence at present available, cannot be satisfactorily determined; but collateral evidence afforded by other sections would seem to lend some support to the view that such is the case.

Whatever view be taken there can be no question that it is on or about the horizon occupied by this band of conglomerate that we find a marked change in the lithological character of the sandstones belonging to the formation under consideration.

During the construction of the Midland Railway (Settle and Carlisle Branch), a cutting of a quarter of a mile, S.E. of Black Leases, through the part occupied by the "496" below the trigonometrical station marked on the One-Inch Map, showed the lower part of the Red Shale series beneath Glacial Drift. These Red Shales were clearly seen to lie on an eroded surface of a series of thin bands of magnesian limestones and dark-grey clays, which evidently belong to the Magnesian Limestone and Plant

Bed Series. The relative positions of these rocks are shown in the annexed figure.*

FIG. 2.—Section on the Midland Railway at Hale Grange, Newbiggin, Westmorland.



Red Shale Series resting on eroded surface of the Magnesian Limestone and Plant Bed Series.

The appearances suggested that the change of physical conditions which led to the deposition of red sandstones and shales in place of the lignites, magnesian limestones, and unctuous dark-grey clays of the older series, was accompanied locally by a certain amount of erosion of the beds below. Contortion of the surface-layers of the rock by the passage of heavy masses of ice would not suffice to account for the phenomena in question.

2. *St. Bees Sandstone*.—This, the highest member of the formation under notice, differs in lithological character from the Penrith Sandstone, and the difference is sufficiently well marked to enable anyone to distinguish between the two even in hand specimens.† The St. Bees Sandstone is well-bedded, finer grained, somewhat darker in colour, usually distinctly laminated, and contains more or less detrital mica. Then again, the crystals formed by secondary quartz, that constitute so marked a feature in the case of the Penrith Sandstone, are here either very rarely developed or entirely absent.

In addition to the above-mentioned differences the St. Bees Sandstone is, taking it all through, thinner-bedded, and is divided up at vertical intervals of every few feet, by irregular and thin beds of shale—a character that, in connexion with the Penrith Sandstone, occurs nowhere except near the very top. Both the shale beds and the sandstone also contain galls of red clay.

Another feature in connexion with the St. Bees Sandstone as well as with the shales that form its natural base, is the presence of irregular decoloration patches here and there throughout the rock; these occur in such a manner that one-half of a block of sandstone belonging to this horizon may be of a uniform dull venetian-red, while the other may be of a pale greenish drab, the

* See also Goodchild, Trans. Cumberland Assoc., No. xvii., and Quart. Journ. Geol. Soc., vol. xxxi. p. 82.

† See also T. V. Holmes, Trans. Cumberland Assoc., No. vii. p. 79.

line of demarcation between the two being often very sharply defined and bearing no relation to the bedding of the rock.

Ripple-marks are common on the bedding-faces of many of the slabs; more rarely sun-cracks, with trails and tracks of organic origin occur, these latter being usually too ill-defined and obscure to afford any satisfactory clue to their precise nature. Rain-prints and pseudomorphic casts of crystals of rock-salt have lately been found in these rocks near Newbiggin, by Mr. Wilbert Goodchild.

The St. Bees Sandstone has been largely used for building-purposes; it works freely, and is obtainable in blocks of larger size than the false-bedded Penrith Sandstone can furnish. There is a large quarry in this stone just north of Newbiggin Hall, at the northern margin of the area. Several smaller quarries occur in and around Milburn, Knock, and Dufton. The rock is tolerably uniform in character over wide areas, so that a description of this rock taken at St. Bees Head, or even in Furness, in North Lancashire, will apply almost exactly to the rock anywhere in the Eden Valley. It is highly probable that the St. Bees Sandstone would prove to be an excellent water-bearing formation, but neither this sandstone nor the Penrith Sandstone has been properly tested in this respect.

At the most only a thickness of a few hundred feet of the St. Bees Sandstone now remains in the area represented by this map; although there is reason for believing that at one time its thickness here may have been nearly two thousand feet. The rock dips at a comparatively low angle, and the width of outcrop between the supposed base of the sandstone and the line where the beds are cut off by the Pennine faults nowhere much exceeds two miles, and is mostly less than that.

J. G. G.

CHAPTER VII.

GLACIAL AND POST-GLACIAL DEPOSITS.

The Glacial deposits consist of the usual admixture of Boulder Clay or Till and Morainic detritus with occasional patches of stratified sand and gravel.

It will be convenient to describe these deposits and kindred matters as they occur in separate districts. We shall therefore first deal with the Glacial phenomena of the Silurian area south of Ullswater; and shall next describe the superficial deposits of the country south of the River Eamont, concluding with those north of that river.

Glacial Deposits on the Silurian Area east of High Street.

The low ground along the course of the River Lowther is thickly covered with Till up to about the 1,000 foot contour: above this level there is but little Drift.

J. R. D.

A small deposit of sub-angular gravel occurs at Bleabeck bridge east of Lodge, at the southern edge of the area, where the road from Shap Wells joins that from Shap to Kendal. It is composed of rudely interstratified sand and sub-angular gravel, most of which consists of decomposed granite. Two oblong patches of gravel exist in Cordale, about one mile above Staingarth. They are raised several feet above the peaty valley-bottom. Cordale Beck cuts into the easterly mound and shows a section of tolerably well-rounded gravel. The westerly mound is entirely turf-covered and the surface is thickly studded with boulders of local rocks.

At Hodgson Hill, north of Waterside, east of Ullswater, there are two small hillocks about twenty-five feet above the level of the lake, near the confluence of Elder and Aik Becks. They are composed of gravel similar in character to that (mentioned on p. 100) which occurs between Knott and Gowbarrow Bay on the north side of the lake.

R. R.

In the heart of the mountains there are several instances of moraines. There are very good ones at the head of Swindale. A section made by the beck in one of these mounds shows the material to be precisely similar to the modern moraines of Switzerland. Another excellent instance of a moraine analogous in shape and disposition to Alpine deposits is at Riggindale Head, where the moraine is mainly composed of blocks derived from Short Stile. Blea Water is surrounded, except on the craggy side, by Drift; but there is no good section; the tarn, however, seems to be partly dammed up by Drift. The rocks at the head of Blea Water are scored with striæ pointing up to the crags: this shows

that small glaciers once clung to these crags, descending straight from them, precisely as small glaciers now come down the sides of the Aiguilles facing Chamouni. It is only of course in special places that signs of this local glaciation, which wound up the age of ice, are to be seen. The striæ generally found on the rocks are due to an earlier and more extensive glaciation. Generally speaking, they run more or less *along* the valleys; and, when the direction of motion can be determined, it is down the dales, showing that the ice-flow had in general a movement from the centre of the fells outwards more or less along the present valleys.

In some few places I have found two sets of striæ on the same rock; thus in Swindale in two instances I found on the same rock scratches pointing N.N.E. and E.N.E., of which the latter are the oldest; but both sets are more or less along the valley.

There are however some exceptions to this longitudinal direction of the glacial striæ: thus in Mosedale below the slate quarries, just outside the limits of this map, we found scratches in the valley bottom pointing S. 15° E. or *across* the valley.

Besides scratches on the rocks, we have instances of grooving on a larger scale, thus in Mardale the spur of High Street known as Dudderwick is crossed by a succession of furrows, more or less along the strike, which are probably due to the action of ice. That the ice has been not only over Dudderwick, but over the higher part of the Rigg called Rough Crag, is shown by boulders perched on the summit of the ridge; one of these is near the Ordnance Station 2,062 feet above sea-level, on the very highest part of Rough Crag. Likewise the spur called Kidsty Howes, formed of rough altered ash, is crossed by furrows trending E. by N., and shows "crag and tail."

Owing to the general similarity of the rocks of the country, boulders do not often afford any indication of the direction in which the ice flowed. The following are exceptional instances, but they are far from being satisfactory. At Rawhead, near Rosgill, a peculiar gritty ash crops out in a ridge alongside the road. A boulder of precisely similar rock is found on the common a little way to the *south*, as if the ice had moved southward, *i.e.* up the valley of the Lowther; but this boulder may not have been derived from the mass of rock now exposed on the roadside.

It was mentioned above (p. 23) that a dyke of fine-grained grey granite is seen in Wet Sleddale for nearly a mile. Boulders of a similar rock are found due north of this dyke near Glede Howe in the Swindale basin. These, if trustworthy, would indicate that the ice had moved northward and *crossed* Wet Sleddale instead of going down it.

Lastly I have found two boulders of a nodular rock, precisely like the nodular bed of Kidsty Pike and Whelter Crags and Drybarrows, far away to the south and east of any known outcrop of that rock: one of these is in Mosedale on the roadside, near the valley bottom, east of the slate quarry; the other is still further south at Harrop Pike at an elevation of over 2,000 feet.

It will be remembered that it is in this neighbourhood that we get the transverse scratches in Mosedale.*

J. R. D.

With reference to the Silurian area between High Street and Ullswater Mr. Hebert writes that clay with large angular stones imbedded in it, occurs along the sides of Bannerdale and Boredale, and upon the low ground bordering the low end of Ullswater. Moraines abound in the neighbourhood of Hayeswater, and in the adjoining valley of Pasture Beck. The small islands in Ullswater and the margin of the lake are well glaciated; but the rocks are seldom of a nature to retain ice-scratches.

Soundings of Ullswater and Hawes Water.

Ullswater.—This nowhere attains a depth of 200 feet. The deepest part occurs opposite Birk Fell one third of the distance across the lake: a uniform depth of over 190 feet is here maintained for a distance of one mile. The lake like many others of glacial origin deepens rapidly as we pass from its head along its length, attains its greatest depth at about one third of its length from its head, and then gradually and slowly shallows until its low end is reached.

E. J. H.

Hawes Water.—This lake is nearly cut in two by a huge fan of torrent-detritus brought down by the Measand Beck and shot into the lake. We here see going on before our eyes a process the like of which has in past time severed Derwent Water from Bassenthwaite Lake, and Buttermere from Crummock Water, and which will surely in time sever the High from the Low Water in the case of Hawes Water. The straits between the two portions of the lake are very shallow, twelve feet being the greatest depth obtained by me in that part. The greatest depth of the Low Water is 49 feet immediately opposite Wallow Crag. The greatest depth of the whole lake is 97 feet in the High Water, where several soundings of from 93 to 97 feet were obtained at about a mile from the head.†

J. R. D.

Glacial Deposits on the Carboniferous Area south of the River Eamont, and west of the Lyvennet.

The Glacial Drift between Crosby Ravensworth Fell and Shap is mainly of that stony nature characteristic of this deposit in most districts lying adjacent to the Fell Country. The matrix in

* Since writing the above, I have been informed by Mr. A. Harker that the felsite associated with the Conistone Limestone between Shap Wells and Long Sleddale is nodular like the Mardale rock.

† See also J. E. Marr, Quart. Journ. Geol. Soc., vol. li. p. 37; and vol. lii. p. 15.

which the larger stones are enclosed consists chiefly of small fragments of stone, and both large and small stones are for the most part derived from local rocks. As a rule the Drift has been removed from the principal ridges and steep escarpments throughout the country occupied by the Carboniferous rocks, while it occurs along the sides and in the bottoms of the river-valleys, and in the hollows between the ridges and bosses of solid rock. Sometimes, however, it has been swept entirely out of either the whole or a portion of a valley, and both the sides and bottom are now quite free from drift, as in the case of the stream west of Waters, near Shap; in other instances, the rock forms one side of the valley while on the other a considerable deposit of drift still exists, as in the case of the country east of Oddendale.

Boulder Clay occurs along the lower flank of the Crosby Ravensworth Fell escarpment, and spreads round both sides of Hardendale Fell towards Thornship on the west, and towards The Nab on the east. It is probable that in this locality the Drift is thicker than it is anywhere else in this immediate neighbourhood. Over much of the Carboniferous area it forms a thin covering only, through which the underlying rocks here and there project.

At Hazel Moor, between the west and east branches of Lyvennet Beck and thence eastwards up to the base of Hollins Scar, the Drift is composed almost entirely of limestone-fragments. On the north side of the westerly branch of Lyvennet Beck there is a bold scar of limestone, while on the south side there is a thick accumulation of local drift. In some places it is very like Till, and altogether has quite a different appearance from mere talus. In the branch of Lyvennet Beck which has its source at the King's Well, south of Hazel Moor, the drift-like character of the deposit is clearly seen. Here it is composed of earthy clay and small stones, and contains boulders, the majority of which are blocks of limestone.

The easterly branch of Lyvennet Beck cuts down through the Drift, and the limestone is exposed both along the sides and in the bed of the stream. Numerous springs and flows of water come out of the limestone on the east side of this branch of the Lyvennet.

The northern slope of Crosby Ravensworth Fell is mostly covered with a thick growth of peat, but as far as the sections extend, they seem to show that the Drift possibly runs well up toward the summit of the ridge and gradually becomes indistinguishable from weathered or decomposed rock.

Boulders of Shap Granite, some of them of very large size, are strewn abundantly over the whole of this district. On many portions of the moorland around Hardendale Fell, and over the country between Waters and The Nab, Shap Granite boulders may be counted by hundreds, if not by thousands. They also occur very numerous on the moorland south and east of Oddendale towards Slack Randy and the Old British Settlement at Ewe Close; in fact, wherever the land is uncultivated these

boulders exist in immense numbers almost to the complete exclusion of boulders derived from the local rocks.

Boulders of Volcanic Ash and Lava do occur here and there but they are very sparingly distributed. Two of the largest boulders measured were as follows :—

Breccia in the alluvium of the Lowther, in Mitchelholm Bottom near Woodhouse west of Clifton Station, 16 feet in length above the grass. Breccia, a mile east of Pooley Bridge, measuring $12 \times 10 \times 6$ feet, and of about five tons weight: others nearly as large occur on the slope below Scrogs Wood.

In this neighbourhood some of the large boulders are known locally as Thunder Stones. This term is generally, though not invariably, applied to blocks of volcanic rock which emit a metallic or ringing sound when struck by the hammer.

Glacial striæ, trending north and south, have been observed near the railway on the watershed above Shap; and at High Lan-kaber striæ have been noticed pointing north-north-west down the valley of the Lyvennet; and Otterstone Crag shows in worn and grooved faces the passage of ice along the Ullswater hollow.

The soil on the reclaimed land is an earthy clay with here and there a slight mixture of peat. Except where it consists of bare rock, the unreclaimed land is usually covered with a layer of mountain peat. Peat is also frequently found in the alluvial flats of the existing streams.

R. R. and W. H. D.

Superficial Deposits near Appleby between the Eden and Lyvennet.

The following are the deposits occurring in this area :—

Post-Glacial	{	Peat.
	{	Alluvium and River-gravel.
	{	River Terraces.
Glacial	{	Till, or Boulder Clay.
	{	Pre- or Inter-glacial (River ?) Gravel.

In the year 1881, or 1882, a tunnel was made opposite the gasworks through Battlebarrow to a lower part of the river, to carry off the sewage of Appleby. It was commenced at the lower or western end and driven E. 18° S. Being at Appleby at the time I was able to watch the progress of the work and this resulted in a discovery of some interest. The tunnel commenced at a little below the surface of the Carboniferous rocks, here reddish sandstones and rather shaly beds, but the upper part was in gravel and very soon the tunnel left the rock and proceeded entirely in clean gravel and sand. In appearance it was exactly like the river-gravel of the present time and could not be distinguished from it. Just at the same time the land above was being drained, and the cuttings for this purpose revealed nothing

but exceedingly stiff red Till, full of limestone and other boulders well covered with glacial scratches: the ordinary Till of the district. A tooth was found in the gravel when the excavations had reached about 300 yards, *i.e.* about three-fourths of the distance, the remainder of the tunnel being as yet unexcavated. This fact precludes, I think, any possibility of accidental introduction. I was also satisfied with the *bona fides* of the workmen, for the find was only elicited by questioning, and a reward for the discovery was not followed with a further supply to meet the demand.

The tooth in question was submitted by me to my friend the late Professor Busk, F.R.S., who pronounced it to be the "molar of a small ox, probably Bison." Whatever it may be it is obvious from its position in gravel under Till, that it existed prior to the last great spread of Glacial conditions in the north of England, and is therefore either of inter-glacial or pre-glacial age. It is more likely of the former age. Bison was found in the Victoria Cave near Settle under glacial beds and also in the Cave at Ray Gill, Lothersdale, near Skipton, but in neither of these cases were the remains found out in the open, but protected by a rock. In this case it is difficult to escape the conclusion that the gravel represents an ancient river-bed which existed in inter-glacial times and was not cleared away by the subsequent grinding of ice-sheet and glacier. It is a most uncommon occurrence in the north-west of England, and indeed so far as I am aware quite unique in that area, to find such beds with the remains of animals in them. Gravels often occur under or intercalated with Till; but without fossil remains it is often impossible to say whether they represent some phase in the ever-shifting conditions of a land- or sea-glaciated area or the normal state of an open river-valley.

In ordinary cases of glacial denudation earlier deposits in valley-bottoms are more often than not removed by the grinding and flow of ice and water going down the valley. The rarity (but for this case I might say the absence) of any pre- or inter-glacial remains in the valleys of the north-west of England is no doubt due to this cause. In this particular case, however, conditions were somewhat different. At the maximum, or rather at a high development of glacial conditions, the passage of ice was not down the Eden valley, but up or across it as, *e.g.* at the time when the Shap Granite boulders were carried across the Pass of Stainmore, and an accumulation of material would be less easily removed in this direction than along the valley seawards. On the mitigation of conditions and the resumption of the ordinary flow down the valley, the earlier river-bed may have been so well covered up by accumulations of material as to escape complete denudation. Some such explanation is necessary to understand this very exceptional occurrence.

Ice-Scratched Rock-Surfaces.—The following Table gives the position of Glacial Striæ on the rock-surfaces at their junction with the overlying drift, and the line of direction of the ice-flow

over them as thereby indicated in the portion of the area which I have surveyed:—

Westmorland 6-inch Map.	—	Direction of Glacial Striæ.
Sheet IX.	250 yards N. of Roman Road in Castrigg Railway Cutting - - -	S.E.
Sheet XV.	660 yards E. of Grayber - - -	E., 25° S.
	On Sandstones near (S.W. of) Barwise Hall (3 places) - - -	S.E.
	500 yards E., 25° S. from Rutter Force on limestone quarry E. of the road - - -	S.E.
	In road 200 yards N.N.W. of Heights Castle - - -	E. 15° S.
	Small quarry 300 yards South of Bladder Pots - - -	S.
	By Scale Beck S.W. of Howe Slack - - -	E., 7° S.
	Another 170 yards higher up Stream - - -	E., 15° S.
	"White Quarry" 670 yards W. of Nags Head Inn - - -	S., 25° E.
Sheet XXII. -	400 yards S. 15° W. from Gathorn Hall above the road - - -	S., 5° E.
	On road to Orton from Appleby 400 yards E. 25° N. from Blasterfield - - -	E., 15° N.
	500 yards S.W. from Whitewall - - -	S.
	180 yards N.E. from Grange Hall, Asby - - -	S., 15° E.

It will be seen that the direction ranges between East 15° North, and South: a range of 105°. If we reduce them to an average we find the prevalent direction to be S.E.

Of course these scratches have been produced at different stages of the growth and flow of glacier and ice-sheet, and not all at the same time; but it is interesting to note that the average direction corresponds with the main direction of the Eden Valley, or the greater valley as bounded by the Lake Hills on the S.W. and the Cross Fell Chain on the N.E.

The grooves on only one of the striation-surfaces point from the region whence Shap Granite boulders, so plentifully scattered here, must have been supplied to this district. This is above Orton Scar, near Blasterfield, on a prominent ridge which may well have stood out of the path of local glaciers when the maximum conditions of ice-accumulation were abating, and have thereby escaped subsequent local glaciation. Shap Granite boulders are very abundant about there.

Till or Boulder Clay.—This is thickly spread over the area under review and lies for the most part in long whale-backed ridges, whose arrangement gives stronger outlines in the district than do the changes in the subjacent rocks. The one-inch maps with hill-shading give a better idea of the form of the ground imparted by this arrangement of material than do the six-inch maps of Westmorland, in which the levelled contours are so sparingly introduced as to be almost useless. It will be seen that these ridges or "drumlins" have a general trend of S. 30° E., which is evidently connected with the direction in which the ice

moved, or with the lines along which it melted with greater or less rapidity: lines which may have been determined by crevasses, ice-movements, carriage of materials, &c.

The Till west and south-west of Appleby is generally of a reddish colour and varies from a very stiff to a sandy clay well packed with boulders of all sizes. These are chiefly of local rocks, though some have travelled fair distances. Shap Granite and other Lake Country rocks are also to be seen, the former in great abundance.

Boulders of Shap Granite occur plentifully along the Eden above and below Crackenthorpe Hall. Along the road from Bewley Castle to Bolton Mr. Goodchild has noted several boulders of Ennerdale Granophyre and one of micaceous quartz-porphry. Shap Granite boulders are also to be seen, and there are many in Teas Sike W. of Bewley Castle. At the house east of Burwain a well was sunk through 33 ft. of Glacial Drift into 9 ft. of grit where a supply of water was found. The Till about here is all more or less red.

In Swinegill Sike, south of Bewley Castle ruins, are many old shafts or shallow diggings similar to shallow coal-workings, but no trace of coal exists. There are many nodules and pebbles of ironstone and reddle in the brook-bottom and in the drift, and it is probable that they formed the object of search. Grey and purple shale is the only rock visible here, dipping N.N.E. at 8°.

Between Hawkrigg and Penny Hill in the next gill east, similar pebbles and nodules occur, and here the rock is Brockram, yellow and red.

In the river-cliffs about Appleby, fine sections in Drift occur—especially at the “Banks.” These are mostly formed of Till of ordinary type with well-scratched boulders of all local rocks, particularly limestone. Several feet of gravel and sand occur in the upper part of the section, but are capped with Boulder Clay. Gravel occurs also in the road south of Appleby Castle, near the turn down to Castle Bank and Bongate Stepping Stones.

Peat occurs occasionally in patches on the alluvium of the river-side, or in little waterlogged hollows between the mounds of Glacial Drift; but it does not attain much thickness or extent in this district. Some of these hollows have probably been tarns either silted up or drained by nature or the farmer. I may mention the alluvial flat at Dryevers and that at Barwise Hall.

In the flat between Crackenthorpe Hall and Bewley Castle ruins, there is a fine clayey alluvium up to five feet thick, overlying peat with trees, about one foot thick, and Boulder Clay, as noted by Mr. Goodchild. He thought the alluvium might make good bricks and tiles.

R. H. T.

Glacial Deposits of the Vale of Eden.

Between Trout Beck and the River Eden the Till is all of the sandy type. As a rule it decomposes into an earthy clay soil. In some instances, as in the vicinity of Brampton, the soil is very

sandy, and it is probable that little, if any, drift exists there. But on the high ground along the Roman Road, the Till is more clayey, and this is also the case in the district north of Appleby. Red Till was seen in a small excavation in the side of the road nearly opposite the Friary, north of Appleby. Although the Penrith Sandstone is extensively exposed in the neighbourhood of Appleby, along the valleys of Brampton Beck and Knock Gill, there are no clear sections showing distinctly the actual character of the Drift. The slopes of the railway-cuttings are soiled over, and grass grown, so that now very little information can be obtained from them; but from such data as do exist, it seems that the red sandy Till is interstratified with irregular beds of sand and gravel and that it is almost entirely of local origin. For while there are boulders and fragments of Shap Granite, and far-travelled rocks from the Lake Country and from Scotland, the majority of the stones and the matrix in which they are contained, are chiefly derived from the rocks in the immediate neighbourhood.

East of the River Eden the district from Temple Sowerby through Kirkby Thore to Long Marton is likewise entirely covered by sandy Till, for the soil is generally of a sandy nature, though sometimes passing into an earthy clay.

The strip of country extending from Newbiggin (Westmorland) by Stamp Hill and east of Long Marton to Dudmire, is occupied by the Red Marls containing gypsum, which lie between the Penrith and St. Bees Sandstones. And here is an instance showing how the character of the Till changes with the character of the rocks on which it rests, as the Till along the area above indicated is composed of red clay and stones. The sections exposed in the Gypsum Pits from Acorn Bank to Stamp Hill all show red Till resting on Red Marls. In the cutting for the Midland Railway near Newbiggin Station, a similar section was seen*; and in the cutting at Hale Hill, Glacial Drift containing lenticular beds of sand was proved to a depth of 30 feet.

From Newbiggin Moor to Milburn Grange and across Knock Moor and Marton Moor to the country around Dufton, sandy Till prevails. In this neighbourhood the St. Bees Sandstone is only exposed in the banks and sides of the valleys, in the stream courses and in an occasional quarry. The Drift, in the vicinity of Moorland Head, Knock Moor, Knock and Birks Head, forms an earthy clay soil, but in the district around Dufton the soil is more sandy, and this is probably due to the proximity of sandstone to the surface. South of Dufton the surface is in some places very stony. Throughout this locality many of the stones lying on the surface are derived from the Silurian rocks along the base of the escarpment, but there are also a considerable number of fragments which have been brought from the Lake Country.

The Silurian rocks are not so universally covered by Glacial Drift. The Till becomes more and more stony as the high ground is approached, and it sometimes passes almost insensibly into the waste from the sub-aerial decomposition of the slates and ashes.

* Goodchild, *Quart. Journ. Geol. Soc.*, vol. **xxxi.**, p. 82.

The high ridge from Knock Pike to the north-east corner of the area is free from Drift.

A thin covering of Drift overlies the Carboniferous rocks north of Milburn Grange and east of Milburn. Here the surface partakes more or less of the nature of the underlying limestones and sandstones which appear at the surface in several places.

The cuttings for the Eden Valley Railway shows the general sandy nature of the Till over the Permian area between Clifton and Appleby. Thus, near to, and east of, Wetheriggs Brick and Tile Works, the drift consists largely of sand and sandstone blocks; of the remaining embedded rock-fragments about one half are Lake Country and the other half Carboniferous rocks; south of Leacet Plantation the surface is reddish and very sandy, weathering white on the top, the sand and the contained blocks of sandstone being apparently derived from the underlying Penrith Sandstone; south of Whinfell Farm the Till contains much sand and sandstone along with Silurian and Carboniferous rocks; south-west of Julian Bower the fragments enclosed in the sandy Till are more or less rolled, and consist mainly of Silurian and Carboniferous, with a few Permian rocks, but towards the middle and deeper parts of the section the Till was more clayey and rested on decomposed Penrith Sandstone at the bottom of the cutting; south of Skygarth the surface is sandy and pebbly, the deposit becoming more clayey deeper down, while the foreign stones are mainly rocks from the Lake Country and some large boulders of Carboniferous Limestone; east of the road near Skygarth the stones are mostly far-travelled and chiefly from the Lake Country, with some blocks of Carboniferous and Permian sandstones.

The country from Eamont Bridge eastwards across Brougham Moor and Whinfell to the River Eden is largely covered by sandy Till. There are, however, considerable areas in the vicinity of Whinfell Forest where the surface consists of actual hard rock or of sand resulting from the decomposition of Penrith Sandstone. The Sandstone lies very near the surface throughout the whole of this district; and consequently the Till is generally sandy, in some instances so much so, that it is scarcely distinguishable from decomposed red sandstone except by the number of foreign stones which it contains. Here and there patches of pure sand occur. These may be portions of the bed of sand which sometimes lies between the Red Sandstone and the sandy Till, or may simply be the result of the decomposition of the rock itself. The far-travelled stones contained in the sandy Till belong chiefly to rocks existing in the Lake Country. These foreign stones occur over the surface of the whole country, existing even on rock-surfaces and in places where the nature of the soil shows that it is entirely derived from the waste of the underlying rocks.

A section in red Till was exposed at the east end of Oglebird Plantation on the west side of the River Eden.

Mounds of Sand and Gravel occur on the south side of the River Eamont, east of Brougham Castle. The largest group lies between Castle Farm and Whinfell. In the banks on the south side of the alluvial flat on the south of the River Eamont the gravel is seen resting directly on the Penrith Sandstone. The Esker mounds extend southwards on both sides of Light Water as far as Haversheaf Hall. Still further south there are other mounds, but these are probably little rock-eminences covered with thin coatings of gravel. Occasionally the surface becomes flat and then the gravel appears to pass gradually into sandy Till, as in the space between Countess Pillar and Moor Houses, but in most instances the boundary between the gravel and the till is more or less sharply defined. At the west end of the river bank close to the road leading to Hornby Hall, and north of Whinfell, gravel immediately overlies Penrith Sandstone. In a similar manner gravel is seen lying on the rock along the east bank of the river, where it bends and flows northwards and finally circles round St. Ninian's Church. Although moundy in places, the surface of the gravel here is in general like that of the gravels which pass insensibly into sandy till.

There are no sections in this locality showing the internal structure of the gravel mounds.

In the low-lying district north-east of the River Eden, there is only one small patch of gravel. It occurs on the south side of Keld Sike and east of Stamp Hill.

Some Esker-like mounds form very conspicuous features in the country which slopes down towards Milburn Beck north of Knock Pike. They are composed of angular and subangular gravel. In the gravel pit on the north side of the road from Knock leading over Fell Pastures, the gravel is angular and coarse but well stratified. The materials forming some of the other mounds seem, while still angular, to be much finer. In this respect they resemble the general character of the Eskers which occur high up in the river-valleys on the western side of the Lake District.

At Cosca Hill on the east side of Knock Gill and south of Great Rundale Beck there is a large mound of fine gravel. It has the characteristic shape, form, and surface outline of a true Esker. Another small mound occurs on the west side of Knock Gill and south of Knock Pike. Much of the smaller and finer material entering into the composition of these mounds consists of Skiddaw Slate fragments.

Superficial Deposits north of the River Eamont.

It has already been mentioned that Glacial Drift exists very generally over the area occupied by the Skiddaw Slates north of the River Eamont (*see* p. 5). In this locality the rock is seldom exposed at the surface except where the small streams have cut their channels down through the surface-deposits into the solid strata below. There are cases, however, other than in brook-

courses, where the Skiddaw Slate does occur at the surface, and in these cases the rock is invariably disintegrated into small fragments and much decomposed. Speaking generally, the country from Rumney's Mead to Gowbarrow Park is almost completely covered by drift; a thin covering most probably it usually is, as the little ravines and brook-channels in which exposures of slate are seen are very rarely of any great depth.

The Till in this neighbourhood is for the most part derived from the slate on which it lies, and consequently it is more like a true Boulder Clay. It consists of stiff blue clay with angular and sub-angular stones, on many of which, especially on the fragments of slate, glacial striæ are strongly marked. Sometimes the fragments of local rocks are so small and so numerous that the matrix in which the scratched stones are contained, is almost entirely composed of them. Close to Ullswater, and especially where the belt of low-lying land adjoining the lake is broad, the Till has been partially re-arranged and is quite like shingle.

Throughout the district which is now being described, the Glacial Beds weather into an earthy clay-soil, forming a medium quality of arable and pasture land.

The more highly elevated land occupied by the Volcanic Rocks, and by the Basement Conglomerate is practically free from Glacial Deposits.

Over most of the country occupied by the Volcanic Rocks the surface is either of hard rocks or of soil derived from the decomposed ash. In the last-named case, it usually forms rough moor-land pasture. North of Great Meldrum and Little Meldrum the low-lying ground across the valley of Blackdike Beck and Matterdale Rigg, up to the base of Great Mell Fell, is covered with red earthy Boulder Clay; and occasionally patches of blue Till are exposed in the brook-sections.

In the localities generally where the Basement Conglomerate exists, it is exceedingly difficult to distinguish the drift-covered areas from those where decomposed rock alone forms the surface, because the soil derived from the one is very similar in character to that derived from the other. There is, however, this distinction, viz., wherever the Boulder Clay is very thin or altogether absent, there is usually very little clayey matter in the soil, and the apparent gravelly nature, as well as the darker red colour, of the ground is most marked. This is the case on the flank of Great Mell Fell, around Little Mell Fell, in the district between Bennet-head Banks and Soulby Fell and at Dunmallard Hill. There are numerous exposures of solid rock throughout these areas, and even when the rock is not exposed, the soil turned up by the plough is precisely like decomposed Red Conglomerate. The Red Conglomerate is also exposed in many of the brook-sections beneath the Boulder Clay.

A thin coating of Drift covers the low ground on both sides of Dacre Beck. It partakes somewhat of the general nature of decomposed conglomerate but is more clayey and contains stones

of a more varied description, many showing traces of ice-striæ. The colour is in this case of a greyish-red tint.

Over the Limestone-area the Boulder Beds sometimes consist of a stiff clay containing stones, sometimes of earthy gravel, and sometimes of beds passing gradually from the one to the other. These gradual passages render the separation of the more clayey from the more gravelly portions of the drift utterly impossible.

Good sections of the Drift are to be seen in the cuttings for the Cockermouth, Keswick and Penrith Railway, between Troutbeck and Penruddock stations. In the cutting north of Cocklakes Hill, the drift consists of—

							Ft.	In.
Surface soil	-	-	-	-	-	-	9	0
Stiff Clay and Stones	-	-	-	-	-	-	2	0
Clay and Gravel	-	-	-	-	-	-	5	6
Clay and Stones	-	-	-	-	-	-		

The Boulder Beds were proved to a depth of 16 feet in the next cutting eastwards towards Penruddock. They were composed of scratched stones and sub-angular gravel in a clayey matrix with many large boulders.

Blue clay under yellow clay, probably only the weathered surface of the blue clay itself, was found in draining the land between Tarn Moss and the road from Penruddock to Matterdale.

North of Whitbarrow Hall, around Kirkbarrow Hall, and on Division Moor the Drift is mostly of the clayey type and forms a stiff clay soil. Around Newbiggin (Cumberland) and eastwards to Penrith it is of a gravelly character, forming light soil, well-suited both for pasture and arable land.

There are considerable areas about Motherby, Penruddock and eastwards to Stainton, where the limestone-rock lies at, or near, the surface. In these instances, as in the case of all limestone-soils, the land is eminently suited for grazing.

North of Ullswater mounds of sand and gravel are very sparingly distributed. Some Esker-like mounds occur at Knott on the north side of the road from Pooley Bridge to Patterdale, and although the moundy form of the surface is confined to the immediate vicinity of Knott, the gravel seems to extend westwards to Gowbarrow Bay.

Brownhow Hill east of Stoddah Bank appears to be a gravel-mound, but there are no sections showing its true character.

Between Swinescales Farm and Swinecales Beck another spread of gravel forms the ridge near the junction of two small valleys. Hereabouts are several gravel pits, but in none of them are the sections very clear. The deposits seem to consist of sand and gravel. In the gravel-pit on the east side of the road from Penruddock to Patterdale, under a thin layer of surface-gravel, 8 feet of sand was seen. On the west of the alluvial flat between the Patterdale road and Cocklakes Hill there are two very tiny gravel mounds. At Beckes Brewery, and on the east side of Skitwath Beck another small patch of gravel occurs.

North of the Penrith road, at Black Hill, a still smaller gravel mound lies close to the outbuildings erected for the small farm occupied by Mr. Geo. Innes. The excavations for the site of these buildings exposed a section showing the composition and structure of the mound. The gravel is coarse; and the pebbles, uniformly about the size of a hen's egg, are embedded in a matrix of sand. This gravel rested on sand in which are some large pebbles. The stratification is inclined 40° in a direction nearly due south.

Gravel also occurs east of Stainton, in isolated mounds and patches extending northwards from the River Eamont. There is a large excavation in one of these gravel-deposits south of the Cockermouth and Penrith Railway, and east of Redhills limekiln. The gravel seems to form part of a series of Eekers which occur in isolated mounds north-westwards by Newton Regny to Kelbarrow.

R. R.

Distribution of Boulders.

While north-west of Ullswater and the River Eamont the Boulders belong to the rocks of the Volcanic Series of the Lake Country generally, there are a few the origin of which can be readily determined as they are rocks of a distinctive character. Thus, Boulders of Quartz Felsite (Microgranite) from St. John's are found west of Penruddock, at Black Hill, and on Greystoke Moor; in the sections exposed in the railway-cuttings for the C. K. and P. Railway, west of Penruddock, many boulders of the same rock are to be seen. Boulders of Volcanic Ash and Porphyry lie scattered around Little Mell Fell, over Watermillock Common and the district northwards. A large boulder of Volcanic Ash now stands at the bank on the north side of the alluvial flat of Dacre Beck, nearly opposite to the place where Greaves Beck enters Dacre Beck from the south. In the fields south of Hutton, fragments of Chiestolite Slate from Skiddaw were observed. And in the northern portion of this district there are fragments of the andesitic lavas of Eycott Hill, in the Glacial Drift.

J. C. W.

Boulders of Shap Granite are of general occurrence throughout the country between Ullswater and the Eamont Valley on the west, and the River Eden on the east, and northwards beyond the limits of the area. They are frequently built into stone-walls, having no doubt been cleared off the surface of the land in the vicinity of the places where they are now found. In many other instances they still remain in the positions which they originally occupied. Many boulders of all kinds have been, however, from time to time, either broken up or removed bodily from one place to another.

The following places may be mentioned as localities where boulders of Shap Granite have been observed. Along the road from Widewath Mill to Helton Flecket; in the district north-east of Helton Flecket; in the neighbourhood of Askham; west of Winder Hall, at the Parish Boundary between Askham and Barton; in the country north and east of Celleron; south of the village of Tirril; in the area close to, and north of, St. Cuthbert's Church, Clifton; on the road from Cliburn near Brownhow; in Melkinthorpe Wood near the place where the paths through the centre of the Wood cross each other; and in the fields known as New Closes; in Gilshaughlin Gill; at the east end of Great Strickland; on Great Strickland Moor, close to Greengill Bank and the village of Morland; on the east side of the alluvial flat of Coal Sike between Low Moor and Mansgrove; near Ousen Stand in the Eden Valley; at the Parish Boundary between Cliburn and Brougham, north of the place first named; and near Culgaith in a field above Hanging Bank on the east side of the River Eden. The portion of this boulder which is seen above ground measures $4 \times 4 \times 5$ feet. There are also many blocks of this rock along the Eden Valley between Temple Sowerby and Appleby; in the gypsum-pits north-east of the Settle and Carlisle Branch of the Midland Railway near Stamp Hill; and in the Valley of Knock Gill east of the village of Knock.

The most notable of the Lake Country boulders which occur east of the Eamont are to be found, so far as known, in the following localities:—A number of large boulders exist in the Heltondale Valley east of Widewath Mill. Boulders of Volcanic Ash and Breccia are seen in the neighbourhood of Wofa Holes on Moor Divock. One of them lying near the Township Boundary measures 7 feet by 7 feet by 3 feet above ground. Another large boulder of volcanic breccia was observed on the top of Ridding Scar, west of Winder Hall, which measured 12 feet by 10 feet by 6 feet. Boulders of volcanic breccia are also found in the hollow north of Abbots Lodge, between Hackthorpe and Clifton. Near Winder Hall, and also west of Tirril, boulders of Diorite occur. South of Tirril a boulder from the Armboth Dyke was seen, and in the same locality a boulder of St. Johns Quartz Felsite was also noted. On Melkinthorpe Moor north of Butts Sike a boulder which may be of St. John's Quartz Felsite lies just north of the alluvial flat. Boulders of felspathic trap may be mentioned as having been seen at the following places:—A boulder 11 feet 6 inches by 7 feet by 3 feet lies north of Highfield, Tirril, and west of the road to Yanwath; in the railway near Brackenber Hill; in the valley of the Leith, close to the east side of the river, south of Melkinthorpe, there is a boulder 10 feet in diameter, and in the same valley, east of Hackthorpe, there is another boulder 14 feet in diameter; in Briddle Sike between Commonholme and Ling; and near Black Leases a boulder 9 feet in diameter was seen.

East of Kirkby Thore and north-west of the road at Bowrang Plantation, there is a boulder which probably has come from Carrock Fell. In the neighbourhood of Milburn and in the country from Fell Pastures through Knock to Dufton, the blocks of Whin Sill are numerous. High up on the western side of Knock Pike are several large boulders of Mica Trap, most likely from one of the adjacent dykes.

Taking the district lying on the north-east of the River Eden as a whole, it may be stated that in addition to the Skiddaw Slate, felspathic Ash, Quartz Conglomerate, Limestone, Grit and Whin Sill from the Pennine escarpment, the foreign stones which most commonly occur in the fence-walls, or on the surface of the ground, are fragments of St. John's Quartz Felsite, Diorite, and Shap Granite.

R. R.

The most noteworthy boulders that occur over the Carboniferous and Permian areas are those of Shap Granite. The distribution

of these has been so fully described by Mr. J. G. Goodchild that we may refer the reader to his papers.* We need only say here that these boulders have been traced right across the Vale of Eden and over the high ground of Stainmore at the head of Lunedale into Yorkshire, along the coast of which county they occur plentifully both in Holderness and also north of Bridlington.

Other important erratics are certain boulders from the Lake Country mentioned by Mr. Goodchild as occurring in the Vale of Eden, viz., the microgranite of St. John's Vale (near Keswick), the Gabbro of Carrock Fell, the granophyric granite of Buttermere, the andesitic lavas of Berrier Nittles and of High Pike in the Caldbeck Fells, the granites of the Calder and Brandy Gill, and the peculiar porphyritic microgranite dyke of Armboth Fell. Mr. Goodchild also mentions as occurring in the Vale of Eden, boulders of the Ennerdale microgranite, and a number of glaciated rocks from Kirkcudbrightshire and Dumfriesshire.

J. R. D.

* Quart. Journ. Geol. Soc., vol. xxxi. p. 55; Trans. Cumberland Assoc., No. xi., 1887.

CHAPTER VIII.

ECONOMICS.

MINERAL VEINS.

Copper.—The Dubhow Copper Mine has never been a successful one ; it was only worked during two years, having been commenced in 1761. The gill to the north, Dubhow Gill, south-east of Patterdale, and west of Angle Tarn, shows frequent nodules of iron-pyrites along its north-west side, and a vein of calcspar may be traced up the gill.

J. C. W.

Two copper veins, one on Burn Banks above Hawes Water, and the other in Guerness Gill at the head of the lake, were once tried with but poor success. (*See also* p. 54.)

Lead Ore.—At Low Hartsop Mine the vein yields Galena with a proportion of silver reckoned at 16 ozs. to the ton ; Copper Pyrites and Zinc Blende also occurring. It is seen at the surface in Pasture Beck, close to the shaft, as a barren quartz-vein. It deviates from the beck to the east, but probably soon regains it, for it is seen more than a mile up the stream as a strong vein of calcspar two feet thick. Its northern continuation is doubtful. The shaft is 30 fathoms deep, and the level runs S. 10° E. for 150 fathoms (1875). The northern level which at one time admitted much water has been drained by a water-wheel pump.

SLATES.

There are two principal horizons along which good slates have been found. The lowest of these is in Cordale, where slates were once got at the Sealhole quarry. The other horizon is the bed of cleaved ash ranging along Mosedale and Wet Sleddale. Good slates occur at several places in this set of beds ; and the chief spots where they have been worked are at the Mosedale quarries, those in Wrengill at the head of Long Sleddale ; and in Kentmere in a band running in a north-east direction from the reservoir house. None of these quarries were being worked when we were in the country, except that in Kentmere below the reservoir.

Slate Pencils.—The Skiddaw Slate was formerly wrought for slate-pencils in Swindale and in Thornship Gill near Shap, and also as before-mentioned (p. 5) on Watermillock Common north of Ullswater. It has already been explained how by a combination of cleavage and close jointing, the rock is adapted for fashioning into slate-pencils.

GRANITE.

The most valuable rock by far in this country is the Shap Granite ; this rock when polished is highly ornamental, and it has

been extensively quarried at Wasdale Crag (in the area to the south) for that and other purposes.

LIME AND CEMENT.

At the works of the Shap Granite Company on the railway near Shap Summit, where large quantities of granite were annually worked up for ornamental purposes, the resulting debris has been converted into granolithic paving and other sorts of stone, by the addition of cement manufactured on the spot from the lower beds of the Carboniferous Limestone. Much of this Carboniferous rock is sandy and some beds contain a large percentage of carbonate of magnesia, preventing their use as cement; but there were also some thick beds of pure bluish-grey rock, which burn to excellent lime.

In a country, in which so much limestone occurs, there is no difficulty in obtaining lime for agricultural and other purposes.

GYP SUM.

A more unique industry is to be found in connexion with the red marls occurring between the Penrith and St. Bees Sandstones, for they contain deposits of gypsum in several places, which have been extensively worked near Kirkby Thore and elsewhere (*see* pp. 80, 84).

BRICKEARTH.

In some places bricks have been made out of the Boulder Clay, as at Wetherriggs and Julian Bower, close to the Eden Valley Railway between Clifton and Temple Sowerby. At the first spot the clay is washed to free it from the sand and stones, which are derived in about equal proportions from Silurian and Carboniferous rocks. At Julian Bower the upper two feet of the section consists of coarse red sand, possibly a wind-drift from the hill of Permian Sandstone in Salter Wood. Beneath this is ordinary stony clay seven feet thick underlaid by clean clay, mottled red and blue in colour, and very tenacious in texture.

J. R. D.

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